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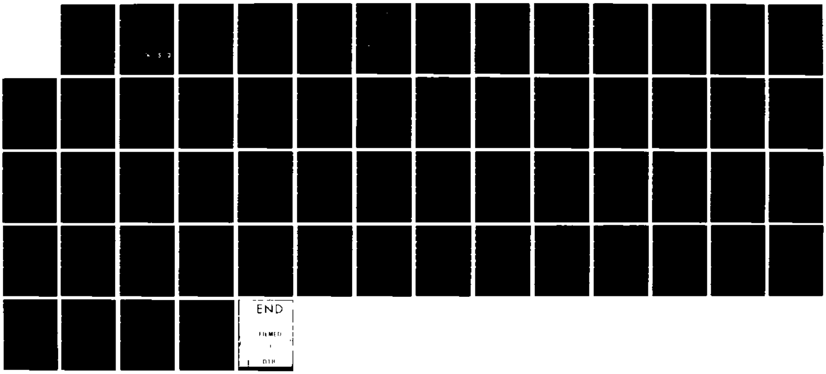

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Lagrangian Current Measurements at Phelps Bank

D. GREENEWALT AND C. GORDON

Ocean Dynamics Branch
Environmental Sciences Division

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An NRL remote sensing experiment was conducted in July 1982 to measure ocean surface manifestations of subsurface topography and hydrography. The central topographic feature in the operational area was Phelps Bank (40° 50'N-69° 20'W). This report presents the results of Lagrangian current measurements made in the vicinity of Phelps Bank during the field exercises.

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LANGRANGIAN CURRENT MEASUREMENTS AT PHELPS BANK

INTRODUCTION

From July 5-25, 1982 scientists from NRL and other laboratories conducted a cooperative, remote sensing experiment. The general purpose of the experiment was to obtain information on oceanographic processes responsible for the surface expression of bathymetry (SEBEX) and hydrography in the wave field and radar imagery of relatively shallow seas. To this end simultaneous and coordinated remote sensing, oceanographic, meteorological, hydrographic and bathymetric measurements were made. The site chosen as the central point for the experiment was Phelps Bank. The bank is a relatively isolated, subsurface, topographic feature located approximately 37 nautical miles southeast of Nantucket Island (40°50'N-69°20'W). Figure 1 shows where the bank appears on the navigational chart (NOAA, 1979).

The field exercise was under the direction of Dr. Davidson Chen (NRL Code 7912C) and Dr. Gaspar Valenzuela (NRL Code 4305). Mr. William Garrett (NRL Code 4333) served as senior scientist aboard the USNS HAYES. The overall plan of the NRL Remote Sensing Experiment has been submitted for publication by Valenzuela (1981) and a review of surface effects attributable to subsurface processes has been published by Chen (1982). This report summarizes the Lagrangian current measurements made during the remote sensing experiment.

BACKGROUND

Among the first investigators to report that radar imagery of the surface waves of shallow seas included features that were related to the bottom topography were DeLoor and Brunsveld van Hulten (1978). The

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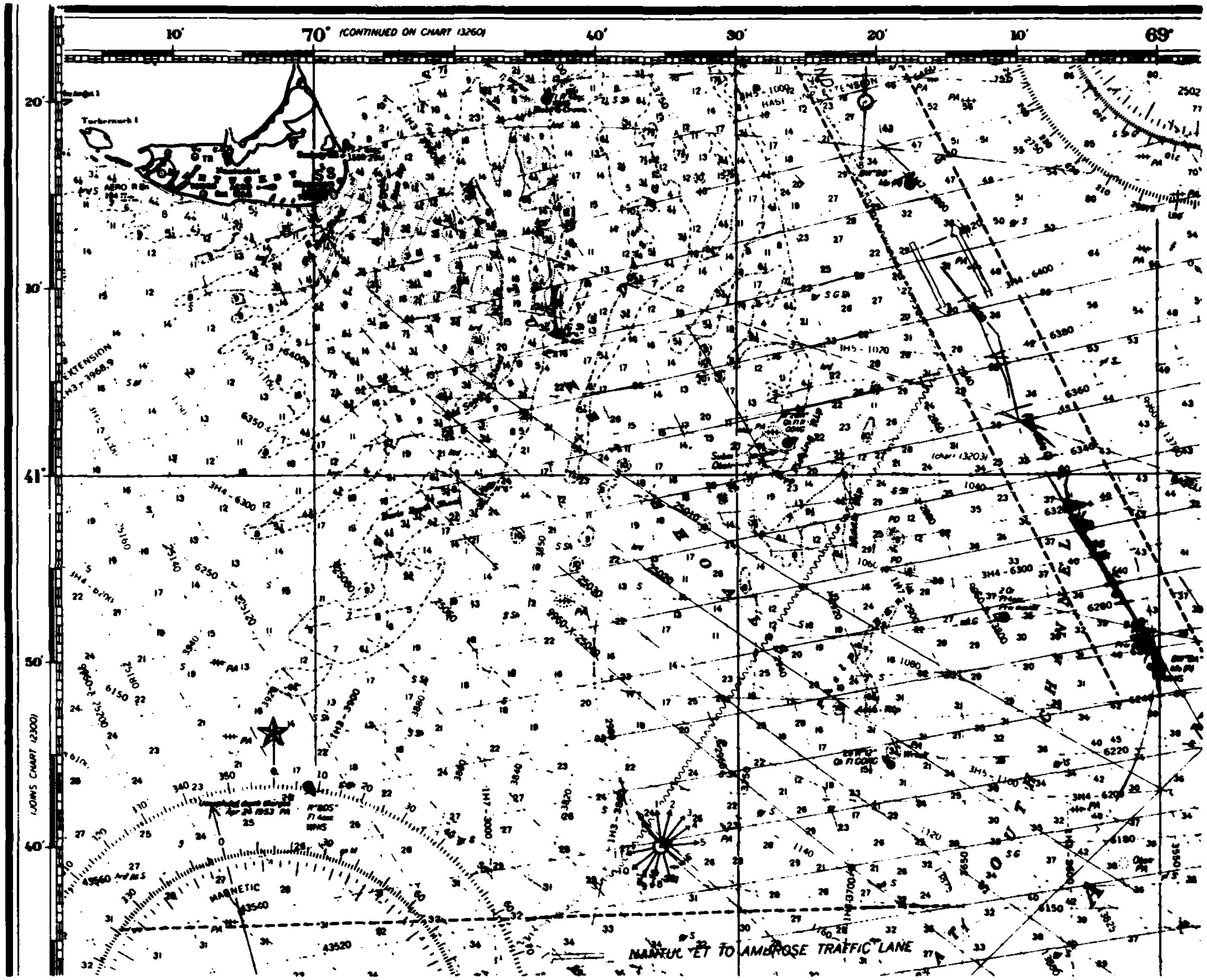

Fig. 1 - A section of the navigational chart showing the location of Phelps Bank (40°50'N-69°21'W) (NOAA Chart 13200, 1979)

phenomenon has been treated in some detail in DeLoor's more recent work (DeLoor 1981). The bottom topography effect has been particularly noticeable in SAR (synthetic aperture radar) imagery from the SEASAT satellite (English Channel and Nantucket Shoals) although airborne SAR and SLAR (side-looking airborne radar) also show the effect. McLeish et al (1981) have published an interpretation of SLAR imagery of surface wave patterns in the North Sea which are related to sea-floor topography. General reviews of radar imagery of the ocean surface may be found in the recent book "Spaceborne synthetic aperture radar for oceanography" Beal et al. eds. (1981) and in Alpers et at. (1981).

In order to interpret surface manifestations of subsurface topography it is necessary to have information regarding the flow of current over and around the particular topographic feature (in this case Phelps Bank). Currents at the site were anticipated to be predominantly rotary tides (1 to 2 knots), based on data provided for the nearest locations in the NOAA Tidal Current Tables published by the U.S. Department of Commerce (NOAA, 1981). The locations provided by the tide tables are Nantucket Shoals 40°37'N-69°37'W; Davis Bank East 41°02'N-69°41'W; and Great South Channel 40°31'N-68°47'W. These locations are 15, 19 and 32 nautical miles respectively from Phelps Bank. The tidal predictions at the three sites are based on the time of maximum flood tide at Pollock Rip which is located approximately 48 nautical miles northwest of Phelps Bank. Progressive vector diagrams of the current speeds and directions were plotted for the three sites. The major axes of the resultant tidal ellipses varied in direction from 345° to 40° and the current speeds ranged between 0.8 and 1.7 kt. for the same tidal phase. This relatively large

variation in both current speed and direction at the locations provided by standard tide tables clearly indicated the need for real-time current measurements at the specific site in question (Phelps Bank).

FIELD MEASUREMENTS

The current measurements described in this report were made using the Lagrangian method, that is, by following the trajectories of tagged water masses. The tags used in this work were "window-shade" drogues. These are essentially sea anchors that follow a specific parcel of sea water along its trajectory. The drogues consisted of 12' x 15' sheets of canvas suspended perpendicular to the current direction. The design of drogues in general and the characteristics of window-shade drogues in particular has been discussed in detail by Vachon (1980).

The drogues used in this work follow previous oceanographic practice in that they consisted of a surface buoy with location aids connected to a subsurface drag element. The primary design criteria included ease of handling during launch and recovery, maintenance of a high, cross-sectional ratio between subsurface and surface elements and low aerodynamic drag on the location aids above the surface. In practice the drogues system weighed less than 100 lb and could be deployed and recovered by a 2 or 3 man crew. The cross-sectional area of the surface float was approximately 1% the projected area of the "window-shade". The design of the above-surface portion of the surface buoy was determined primarily by the requirements of the locating aids, since the line-of-sight ranges of the radio beacon, flasher and radar reflector depend on the height above the sea. In order to keep the aerodynamic drag of the system to a minimum Luneberg lenses were used as radar reflectors. The 20.3 cm diameter

spherical lenses provide a radar return signal equivalent to a 2 m^2 reflector. These reflectors were mounted on a 3.8 cm diameter aluminum mast approximately 1.75 m above the sea surface.

Radio beacons were mounted above the Luneberg lenses. Each beacon broadcast on a specific frequency between 150 and 168 MHz. Since a multi-channel radio-direction finder (selecting these frequencies) was used, the beacons could be both located and identified simultaneously. The radio beacons were Ocean Applied Research Model ST-341 submersible VHF/FM, 250 milliwatt transmitters. An OAR Model ADF S-320-400 automatic direction finder with 10 crystal-controlled channels was used for locating and identifying the drogues. Standard flashers with xenon gas discharge lamps (.01 watt/sec) were mounted on the mast for visual location at night. The surface buoy flotation consisted of two standard, office waste baskets filled with self-expanding urethane foam (ISOFOAM-PE2).

The hydrodynamic and aerodynamic forces acting on the drogue system were calculated using the standard drag force equation:

$$F = \frac{1}{2} \rho C_D AV^2$$

where ρ is fluid density, C_D is the drag coefficient, A the projected cross-sectional area and V^2 is velocity squared. The wind drag on the above-surface components of the buoy for a 20 knot wind is equivalent to a 1.0 cm/sec current acting on the subsurface drag element while a 10 knot wind corresponds to 0.5 cm/sec assuming $C_D = 1.93$ for a window-shade drogue. Figure 2 shows an estimated performance curve for a window-shade drogue taken from the work of Vachon (1974). The diagram takes into account the effects of area and ballast weight. In the case of the

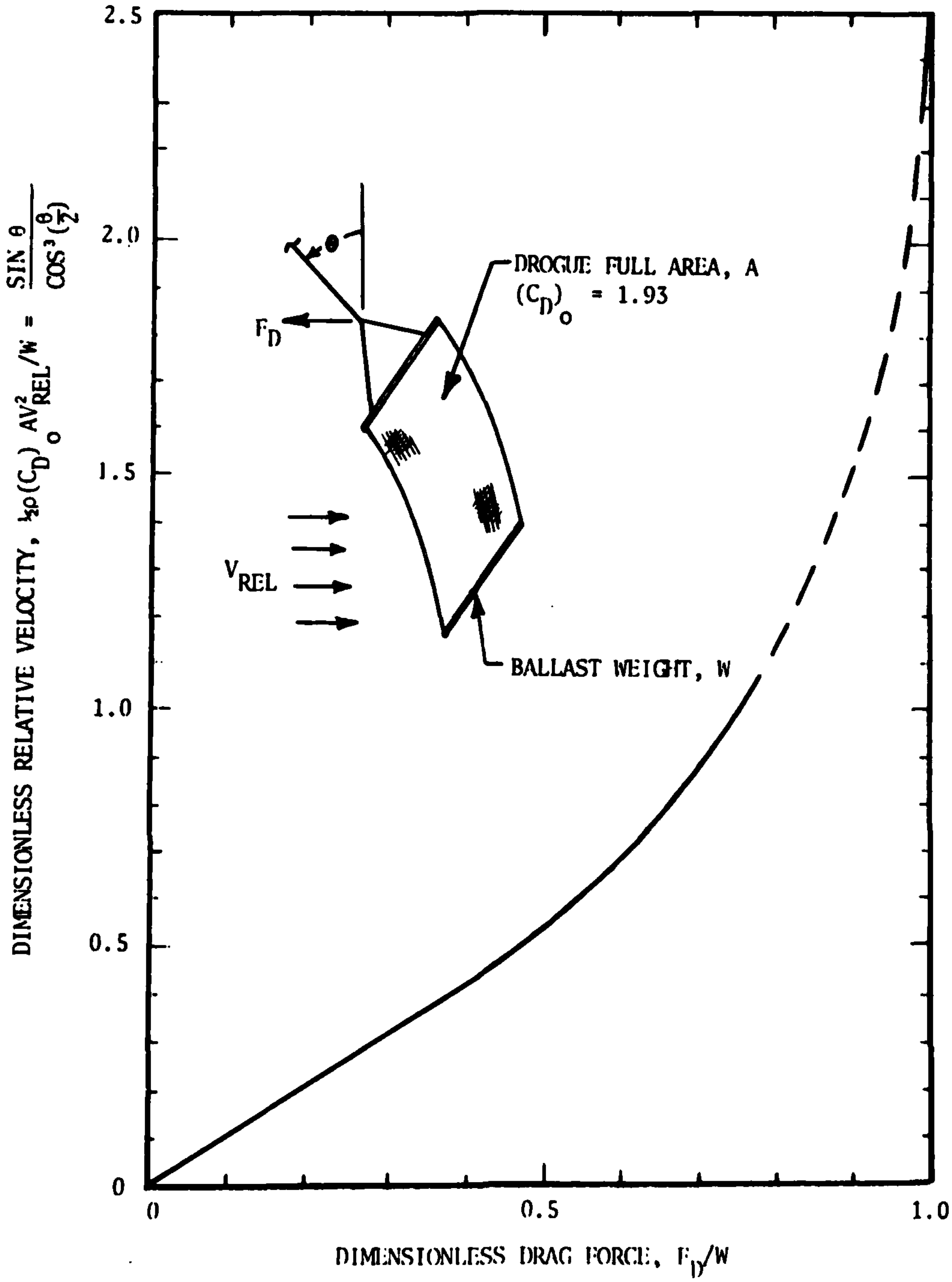

Fig. 2 - Performance curve for a window shade drogue (Vachon, 1974).

drogues used in these measurements, the ballast weight was about 8 kg. According to Vachon, the performance curve is adequate for steady-flow drag forces up to about 75% of the ballast weight. A properly sized and ballasted drogue will remain on the linear part of the curve when horizontal drag forces are less than one half the ballast weight. That is, the drogue will not stream upward in the flow. Detailed discussions of the forces acting on drogues of this type may be found in the work of Kirwan et al (1975).

For purposes of the present work, the use of Lagrangian drogues has the advantage of allowing horizontal patterns of the flow to be readily visualized over a large area. This permits correlation with bathymetric data for possible topographic dependence. A disadvantage of the Lagrangian method is that it occupies ship time and for this reason, the time series of current measurements is usually shorter than may be obtained from a moored system of current meters. This objection has been largely overcome in recent years by remotely sensing buoy positions from satellites (Molinari et al, 1981; Richardson, 1981; McNally, 1980; Kirwan et al, 1978; Cresswell, 1977).

The Lagrangian current measurements were conducted in two areas centered about 4 miles west (July 10-11) and 8 miles east (July 18-19) of Phelps Bank. The drogues covered an area of the sea approximately 80 square miles. After deployment, the drogues were sequentially located using radar, radio direction finding and projected drogue paths. The drogues were visually sighted and their position fixed with LORAN-C (Northstar Model 7000). These sequential sightings were then used to establish the trajectories of the drogue. It should be noted that LORAN-C coverage

in the area is exceptionally good. Estimates based on the consistency of LORAN fixes indicate that one-minute averaged, relative positions are good to about 100 m. The records of the times and positions in the sequence of drogue sightings are given in Tables 1 and 2. In Table 1 five drogues were followed west of Phelps Bank with an average time between sightings of a particular drogue of approximately 1 hour and 20 minutes. All drogues except C were centered at a depth of 6 m; C was at 18.2 m. In Table 2 one drogue at a time was tracked east of the bank with more frequent sightings. The average interval between LORAN-C fixes in this case was about 28 minutes and both drogues were at 6 m depth. Dur ; each drogue following, the weather conditions remained relatively scant. On July 10-11, 1982, winds at 10 m height were light (3 ± 1 msec d variable in direction. On July 18-19, 1982, there was a steady fresh wind (8.8 ± 0.6 msec^{-1}) out of the southwest (220° ± 8°). There was moderate to heavy fog on both occasions.

The drogue sightings recorded in Tables 1 and 2 are plotted in Figures 3 through 8. Figures 3 through 7 represent current flow west of Phelps Bank and the currents to the east of the bank are shown in Figure 8. The drogue trajectories connecting the plotted sighting times are qualitative estimates. Trajectories where sightings were infrequent are shown as dashed lines in Figure 3 through 7 and are more speculative than the solid lines. The sightings in Figure 8 were more frequent and the trajectories are plotted point to point. More detailed interpolation was obtained by computer processing of the data during appropriate segments of the drogue paths. The computer assisted results will be discussed further on in this report.

Table 1. Drogue Locations (LORAN-C) July 10-11, 1982

TIME (U.T.)	N. LATITUDE	W. LONGITUDE	DROGUE
1418	40° 45.85'	69° 30.31'	A
1430	40° 46.01'	69° 30.59'	A
1440	40° 46.35'	69° 30.67'	A
1516	40° 46.51'	69° 28.51'	B
1532	40° 45.82'	69° 29.70'	C
1546	40° 44.99'	69° 30.57'	D
1608	40° 44.95'	69° 28.23'	E
1647	40° 48.89'	69° 28.39'	B
1656	40° 50.09'	69° 29.17'	A
1715	40° 48.04'	69° 28.18'	C
1728	40° 46.98'	69° 29.15'	D
1747	40° 46.80'	69° 26.32'	E
1805	40° 48.73'	69° 26.95'	C
1820	40° 50.89'	69° 26.34'	B
1826	40° 51.74'	69° 26.57'	A
1859	40° 47.81'	69° 26.93'	D
1912	40° 47.68'	69° 24.12'	E
1925	40° 48.90'	69° 25.15'	C
1941	40° 51.15'	69° 24.38'	B
1947	40° 51.15'	69° 24.38'	A
2021	40° 47.27'	69° 25.14'	D
2041	40° 47.06'	69° 21.74'	E
2058	40° 47.96'	69° 23.60'	C
2115	40° 49.95'	69° 23.20'	B
2121	40° 50.76'	69° 23.17'	A
2155	40° 45.10'	69° 24.18'	D
2216	40° 45.17'	69° 20.64'	E
2232	40° 46.04'	69° 23.09'	C
2248	40° 47.90'	69° 23.36'	B
2255	40° 48.62'	69° 24.29'	A
2329	40° 43.71'	69° 24.36'	D
2349	40° 43.01'	69° 21.17'	E
0016	40° 44.23'	69° 24.13'	C
0030	40° 46.15'	69° 24.91'	B
0038	40° 46.80'	69° 26.15'	A
0114	40° 42.42'	69° 25.92'	D
0134	40° 41.34'	69° 22.99'	E
0202	40° 42.45'	69° 26.36'	D
0213	40° 43.78'	69° 25.89'	C
0228	40° 46.06'	69° 26.98'	A
0257	40° 42.88'	69° 26.93'	D
0318	40° 41.00'	69° 24.66'	E
0347	40° 43.39'	69° 26.87'	D
0359	40° 45.14'	69° 26.34'	B
0425	40° 48.65'	69° 28.88'	A

Table 1. (continued)

TIME (U.T.)	N. LATITUDE	W. LONGITUDE	DROGUE
0614	40° 49.69'	69° 25.96'	B
0619	40° 49.72'	69° 26.02'	B
0659	40° 47.93'	69° 24.72'	C
0722	40° 45.35'	69° 24.42'	D
0755	40° 41.25'	69° 23.57'	E
0801	40° 41.26'	69° 23.39'	E
0857	40° 40.33'	69° 23.43'	E
0911	40° 39.88'	69° 23.42'	E
0959	40° 43.06'	69° 24.84'	D
1022	40° 42.51'	69° 25.37'	D
1052	40° 45.94'	69° 26.13'	C
1058	40° 45.89'	69° 26.30'	C
1112	40° 46.43'	69° 27.48'	B
1120	40° 46.22'	69° 27.31'	B
1131	40° 46.53'	69° 29.61'	A
1139	40° 46.46'	69° 29.87'	A

Table 2. Drogue Locations (LORAN-C) July 18-19, 1982

TIME (U.T.)	N. LATITUDE	W. LONGITUDE	DROGUE
1016	40° 49.91'	69° 13.04'	B
1034	40° 50.43'	69° 13.17'	B
1128	40° 52.02'	69° 12.86'	B
1136	40° 52.26'	69° 12.71'	B
1144	40° 52.51'	69° 12.67'	B
1243	40° 54.34'	69° 11.77'	B
1322	40° 55.29'	69° 10.84'	B
1336	40° 55.53'	69° 10.53'	B
1414	40° 55.96'	69° 09.62'	B
1429	40° 55.97'	69° 09.24'	B
1449	40° 56.06'	69° 08.86'	B
1518	40° 55.91'	69° 08.27'	B
1626	40° 54.84'	69° 07.33'	B
1703	40° 53.97'	69° 06.96'	B
1731	40° 53.40'	69° 06.89'	B
1757	40° 52.71'	69° 06.75'	B
1822	40° 52.21'	69° 06.77'	B
1858	40° 51.43'	69° 06.87'	B
1921	40° 51.09'	69° 07.15'	B
1944	40° 50.83'	69° 07.37'	B
2005	40° 50.71'	69° 07.75'	B
2050	40° 50.73'	69° 07.78'	B
2115	40° 51.04'	69° 08.12'	C
2147	40° 51.43'	69° 08.23'	C
2215	40° 51.93'	69° 08.21'	C
2243	40° 52.58'	69° 08.30'	C
2255	40° 52.88'	69° 08.19'	C
2315	40° 53.25'	69° 08.25'	C
2335	40° 53.98'	69° 08.14'	C
0011	40° 55.07'	69° 08.02'	C
0037	40° 55.91'	69° 07.63'	C
0108	40° 56.57'	69° 07.41'	C
0130	40° 56.96'	69° 07.03'	C
0159	40° 57.40'	69° 06.84'	C
0221	40° 57.59'	69° 06.45'	C
0255	40° 57.63'	69° 06.54'	C
0316	40° 57.42'	69° 06.29'	C
0347	40° 57.16'	69° 06.53'	C
0411	40° 56.59'	69° 06.54'	C
0447	40° 55.80'	69° 06.80'	C
0506	40° 55.16'	69° 06.84'	C
0549	40° 53.79'	69° 07.39'	C
0637	40° 52.07'	69° 07.78'	C
0707	40° 51.21'	69° 08.29'	C
0732	40° 50.41'	69° 08.61'	C

Table 2. (continued)

TIME (U.T.)	N. LATITUDE	W. LONGITUDE	DROGUE
0815	40° 49.53'	69° 09.54'	C
0858	40° 48.82'	69° 10.36'	C
0923	40° 48.68'	69° 10.69'	C
0952	40° 48.78'	69° 11.41'	C
1015	40° 48.95'	69° 11.50'	C
1038	40° 49.19'	69° 11.84'	C
1100	40° 49.34'	69° 11.68'	C
1125	40° 50.01'	69° 11.78'	C
1149	40° 50.38'	69° 11.62'	C
1230	40° 51.66'	69° 11.35'	C
1302	40° 52.50'	69° 10.96'	C

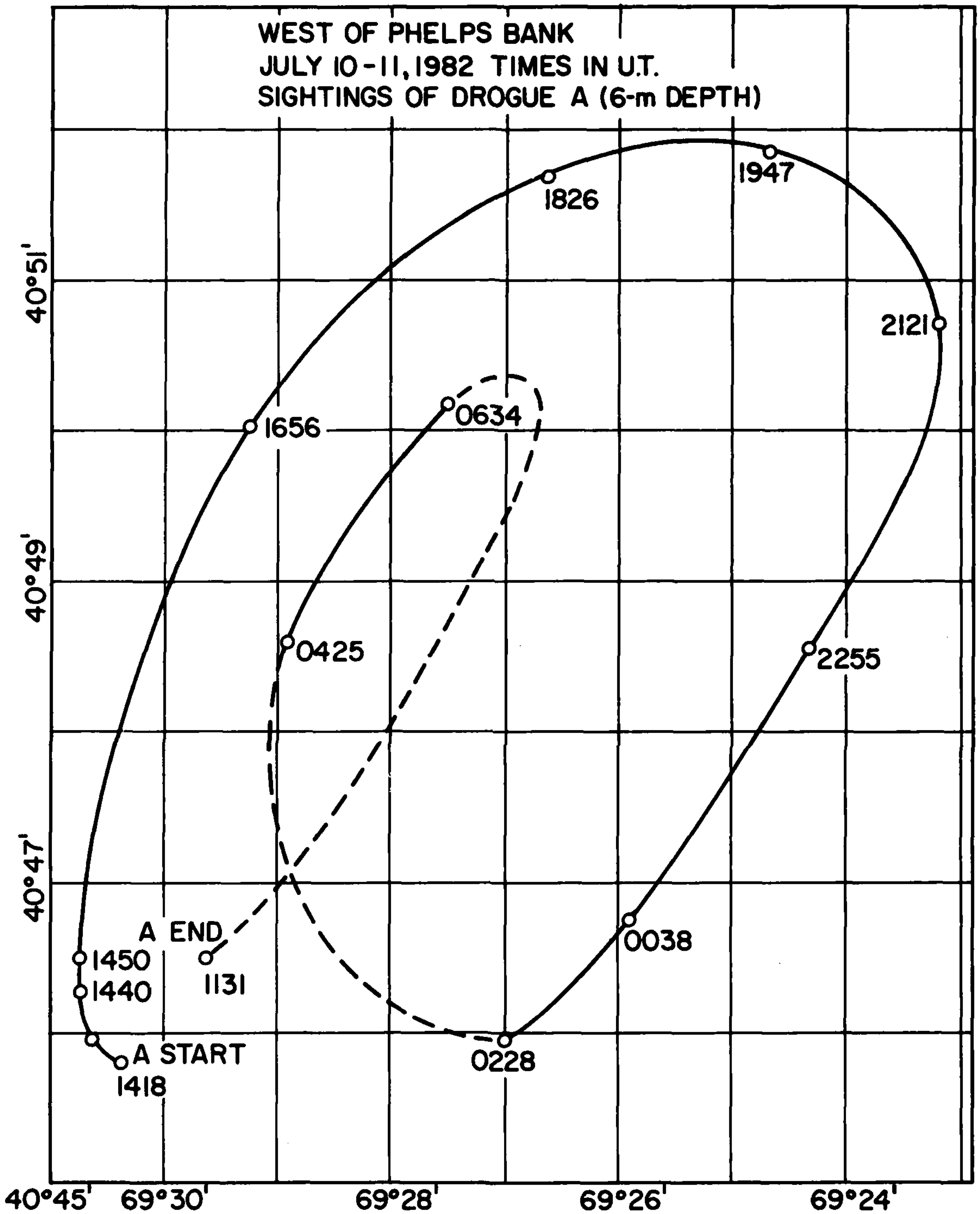

Fig. 3 - Probable path of drogue A (fit by eye) 1418 July 10 - 1131 July 11, 1982.

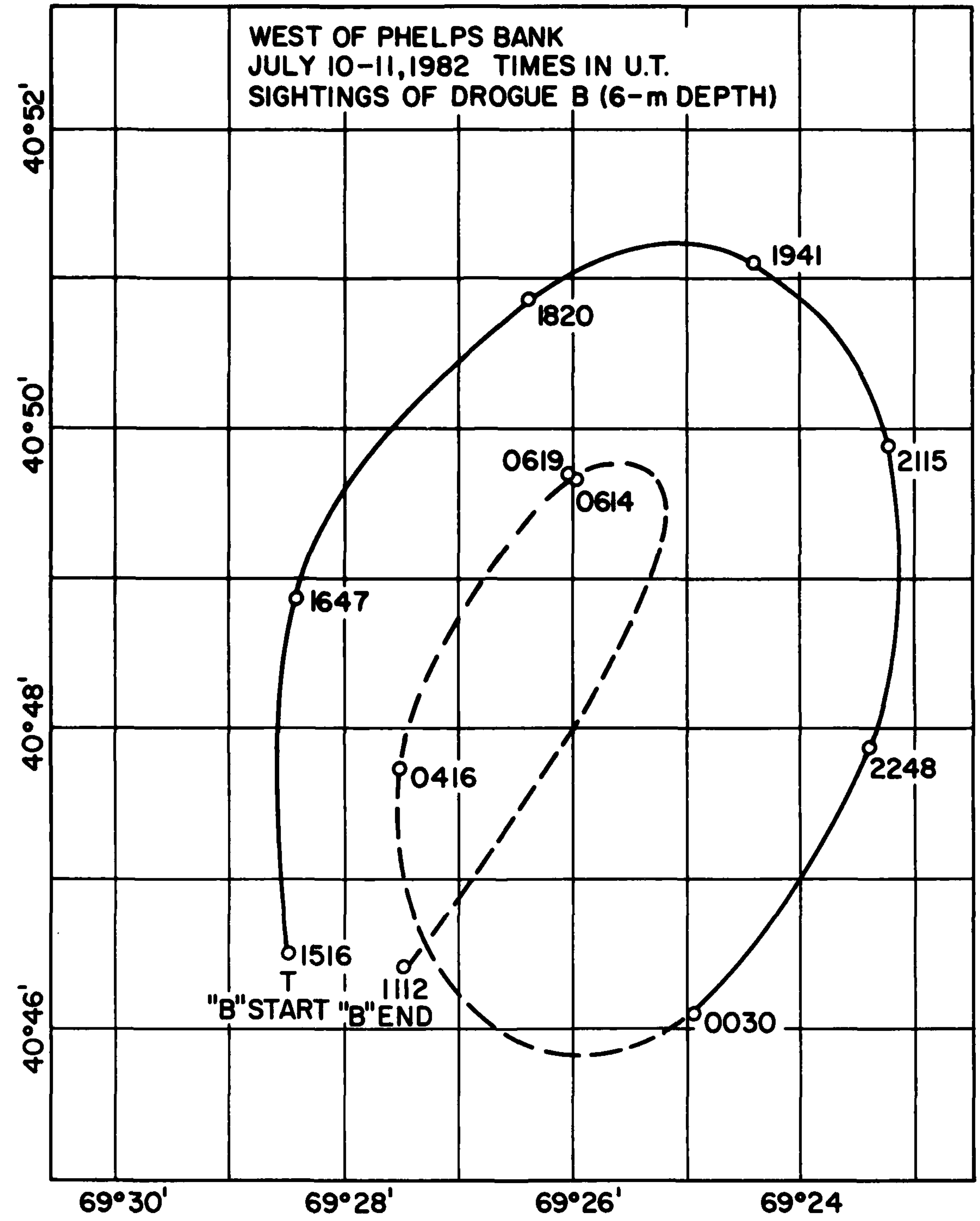

Fig. 4 - Probable path of drogue B (fit by eye) 1516 July 10 - 1121 July 11, 1982.

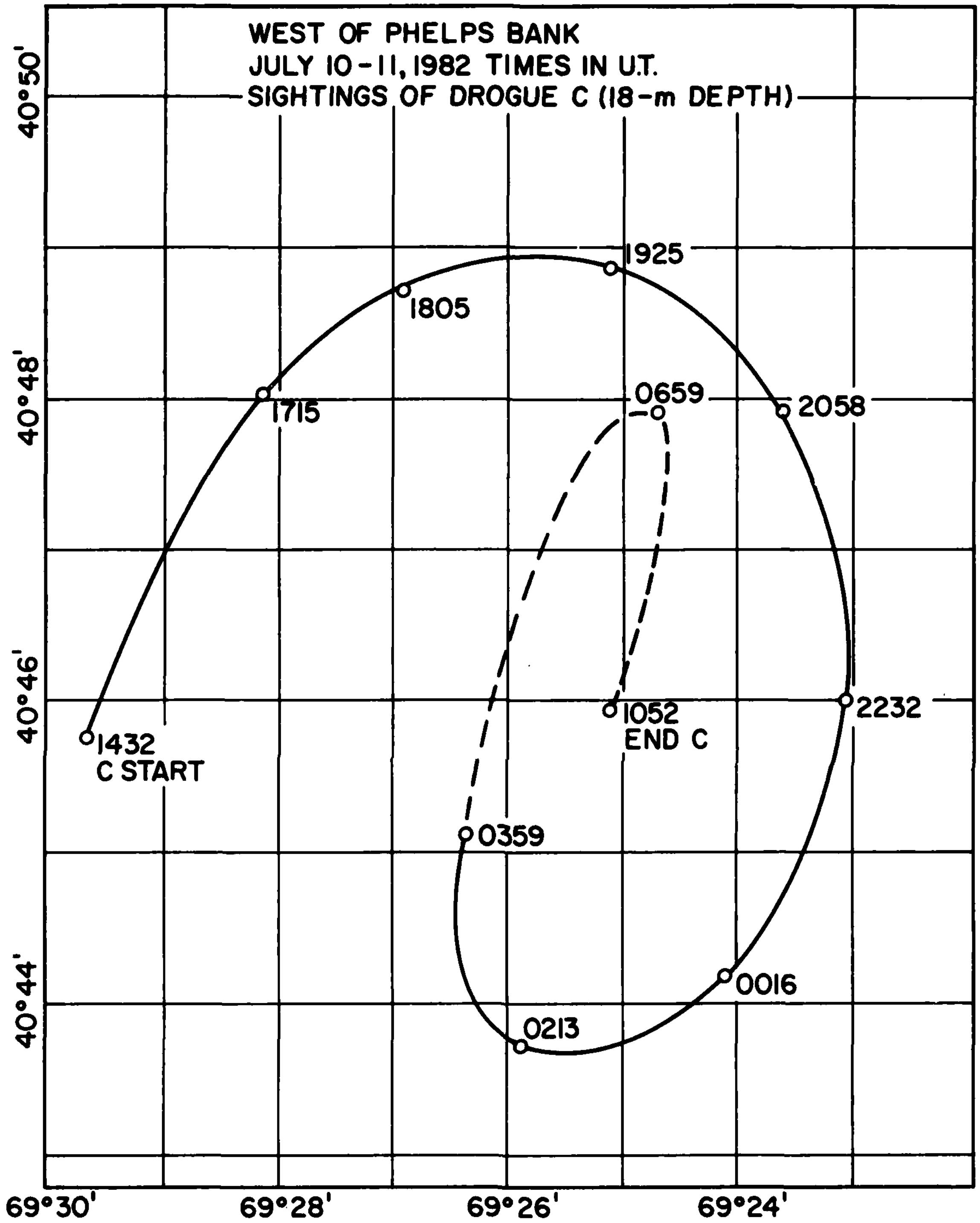

Fig. 5 - Probable path of drogue C at 18 m depth (fit by eye) 1432 July 10 - 1052 July 11, 1982.

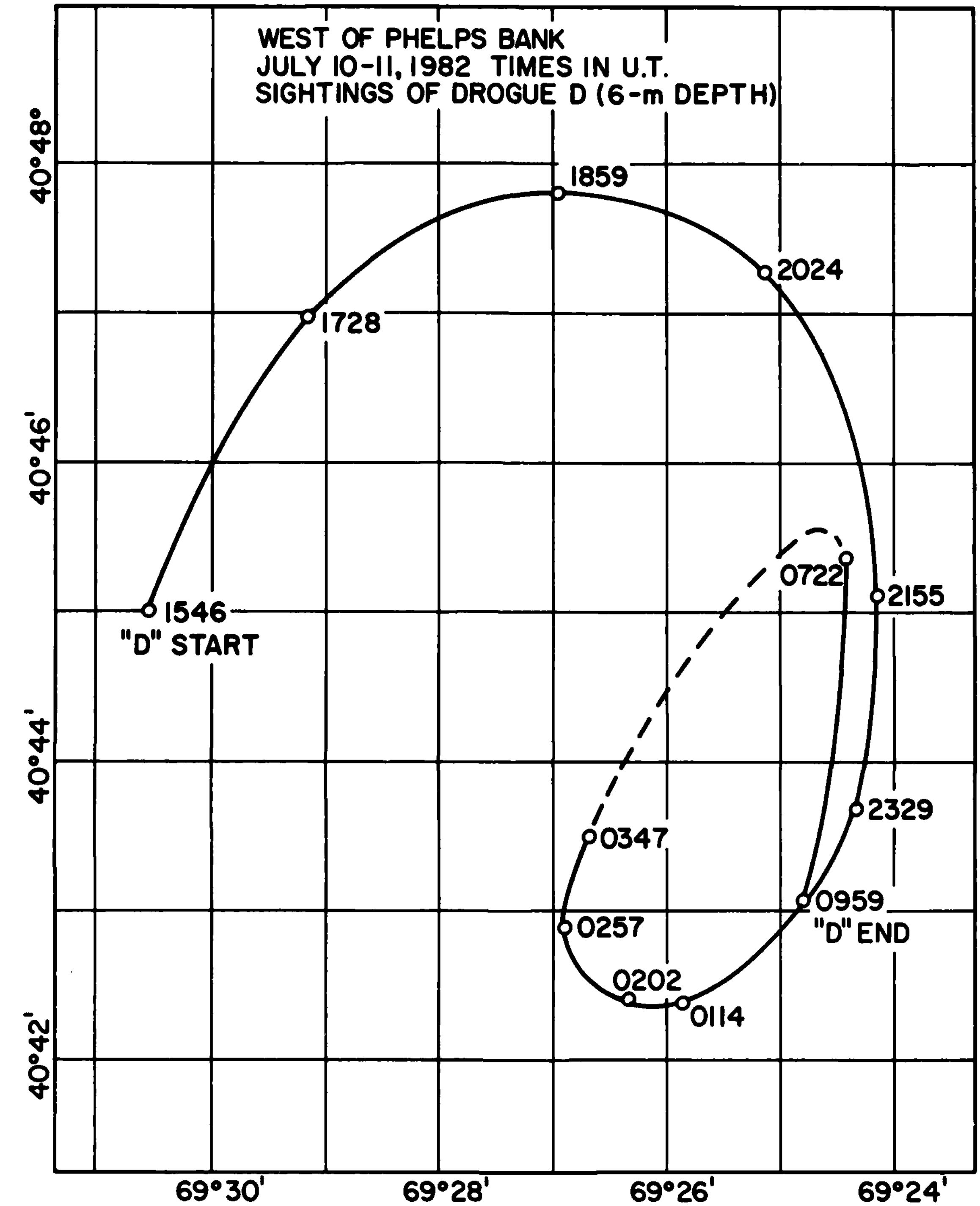

Fig. 6 - Probable path of drogue D (fit by eye) 1546 July 10 - 0959 July 11, 1982.

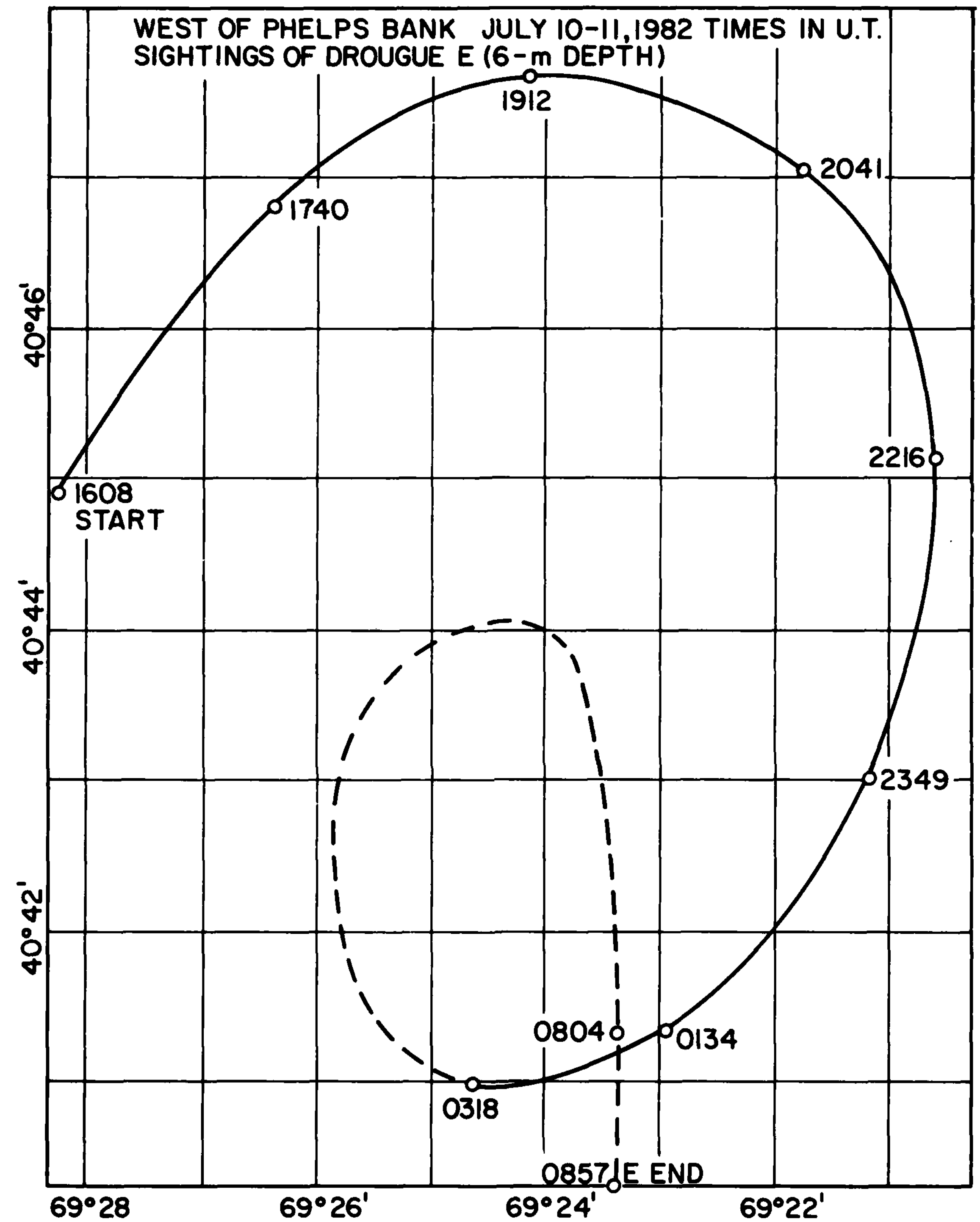

Fig. 7 - Probable path of drogue E (fit by eye) 1608 July 10 - 0857 July 11, 1982.

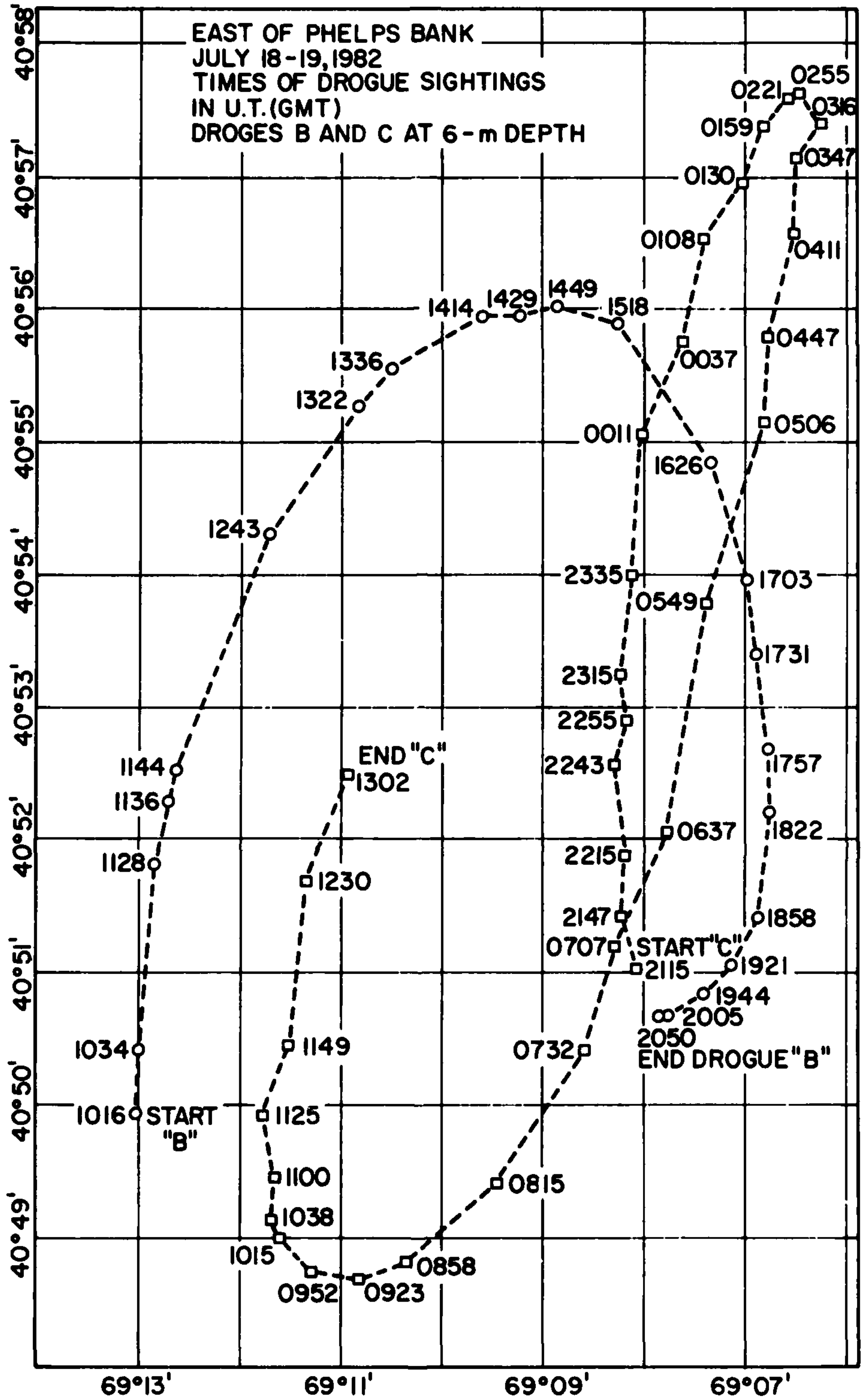

Fig. 8 - Probable path of drogues B and C (fit by eye) 1016 July 18 - 1302 July 19, 1982

It should be noted that the drogue trajectories show considerable variation even though they are displaced from each other by only a few miles. For example, in Figures 3 through 7 the minor axis of the "tidal ellipse" increases relative to the major axis as one progresses in an easterly direction towards Phelps Bank, that is, Drogue A through Drogue E. As previously mentioned, drogue C was following the current flow at a depth 12 meters deeper than the other 4 drogues. This was for purposes of measuring vertical current shear. No significant difference is evident in the trajectory of drogue C that could be related to depth. Drogue C moves slightly slower than the average of all the drogues (1.12 kt as opposed to 1.19 kt), however, this difference is not statistically significant when using point-to-point, graphical estimates of current speed. Computer treatment of the data indicates that there is a measurable vertical shear between 6 m and 18 m depth during these measurements.

Based on the current speeds and directions calculated from the intervals between drogue sightings (point-to-point interpolation), a "tide table" for the vicinity of Phelps Bank can be produced. This basic information on current speeds and directions was obtained graphically for the various drogues and is shown in Tables 3 through 9.

Table 3. Drogue A, July 10-11, 1982 (6m depth)

TIME (U.T.)		Current	Current
Start	End	Speed (kt.)	Direction (deg)
1418	1430	1.3	307
1430	1440	1.98	347
1440	1450	1.44	001
1450	1656	1.76	018
1656	1826	1.73	050
1826	1947	1.11	084
1947	2121	1.02	136
2121	2255	1.46	202
2255	0038	1.25	214
0038	0228	.63	227

Table 4. Drogue B, July 10-11, 1982 (6m depth)

TIME (U.T.)		Current	Current
Start	End	Speed (kt.)	Direction (deg)
1516	1647	1.55	002
1647	1820	1,61	038
1820	1941	1.11	080
1941	2115	.95	144
2115	2248	.129	184
2248	0030	1.23	213

Table 5. Drogue C, July 10-11, 1982 (18m depth)

TIME (U.T.)		Current	Current
Start	End	Speed (kt.)	Direction (deg)
1932	1715	1.48	027
1715	1805	1.39	053
1805	1925	1.01	083
1925	2058	1.04	130
2058	2232	1.16	168
2232	0016	1.16	203
0016	0213	.72	250
0213	0359	.79	346
0359	0659	1.02	024

Table 6. Drogue D, July 10-11, 1982 (6m depth)

TIME (U.T.) Start	End	Current Speed (kt.)	Current Direction (deg)
1546	1728	1.32	029
1728	1859	1.28	064
1859	2021	1.06	111
2021	2155	1.46	161
2155	2329	.89	186
2329	0114	1.00	223
0114	0202	.44	274
0202	0257	.71	315
0357	0347	.72	016
0347	0722	.71	043

Table 7. Drogue E, July 10-11, 1982 (6m depth)

TIME (U.T.) Start	End	Current Speed (kt.)	Current Direction (deg)
1608	1747	1.45	037
1747	1912	1.34	063
1912	2041	1.28	110
2041	2216	1.33	156
2218	2349	1.39	.92
2349	0134	1.23	220
0134	0318	.78	254

Table 8. Drogue B, July 18-19, 1982 (6m depth)

TIME (U.T.) Start	End	Current Speed (kt.)	Current Direction (deg)
1016	1034	1.67	003
1034	1128	1.96	005
1128	1136	3.77	012
1136	1144	1.46	012
1144	1243	1.96	022
1243	1322	1.85	034
1322	1336	1.57	041
1336	1414	1.25	060
1414	1429	1.20	088
1429	1449	.85	075
1449	1518	1.02	108
1518	1626	1.11	146
1626	1703	1.52	163
1703	1731	1.19	174
1731	1757	1.67	174
1757	1822	1.12	178
1822	1858	1.32	186
1858	1951	1.11	210
1921	1944	.79	223
1944	2005	.86	241

Table 9. Drogue C, July 18-19, 1982 (6m depth)

TIME (U.T.) Start	End	Current Speed (kt.)	Current Direction (deg)
2115	2147	.74	343
2147	2215	.96	003
2215	2243	1.47	354
2243	2255	1.75	016
2255	2315	1.06	352
2315	2335	2.27	007
2335	0011	1.85	004
0011	0039	1.64	024
0039	0108	1.65	012
0108	0130	1.38	035
0130	0159	.96	020
0159	0221	.73	041
0221	0255	.14	061
0255	0316	.77	144
0316	0347	.60	215
0347	0411	1.42	181
0411	0447	1.35	194
0447	0506	2.03	182
0506	0549	1.99	197
0549	0637	2.22	190
0637	0707	1.88	204
0707	0732	1.95	197
0732	0815	1.68	214
0815	0858	1.26	224
0858	0923	.90	248
0923	0952	.75	280
0952	1015	.87	317
1015	1038	.42	334
1038	1100	.84	004
1100	1125	1.17	349
1125	1149	1.35	020
1149	1230	1.82	007
1230	1302	1.68	021

Since the tidal period is rather constant, the tide table can be related to the tidal phase at a particular location. In this case, we will relate the tides to maximum flood at Pollock Rip, as is done in the NOAA Tidal Current Tables (NOAA, 1981). The method used here for producing tide tables was to plot the speeds and directions of the currents given in Tables 3 through 9 as a function of the time after maximum flood current at Pollock Rip. From observation of the plots, an overall variability of these parameters as a function of time can be estimated.

The speeds and directions for the five drogues followed west of Phelps Bank (A,B,C,D,E) are shown in Figures 9 and 10; those for the two drogues tracked east of the bank are presented in Figures 11 and 12. All the curves were fit by eye to unprocessed raw data. At first glance, it appears from these figures that the current direction is much more regular and predictable than the current speed. The current direction is apparently predictable to less than ± 10° in all cases, whereas current speeds at a given time may vary by as much as a factor of 2 in the "worst case". However, statistical treatment of the data in Figure 9 shows that the average deviation of current speed from the mean at a given hour is only ± 10%. Since there were only two drogue measurements east of the bank (Figure 11), no statistical parameters were calculated. It should also be noted here, as a caution, that Figure 9 represents one tidal ellipse as followed by 5 drogues while Figure 11 represents 2 tidal ellipses followed by a single drogue. For this reason, there is some space-time ambiguity in interpreting the variability shown in these two figures.

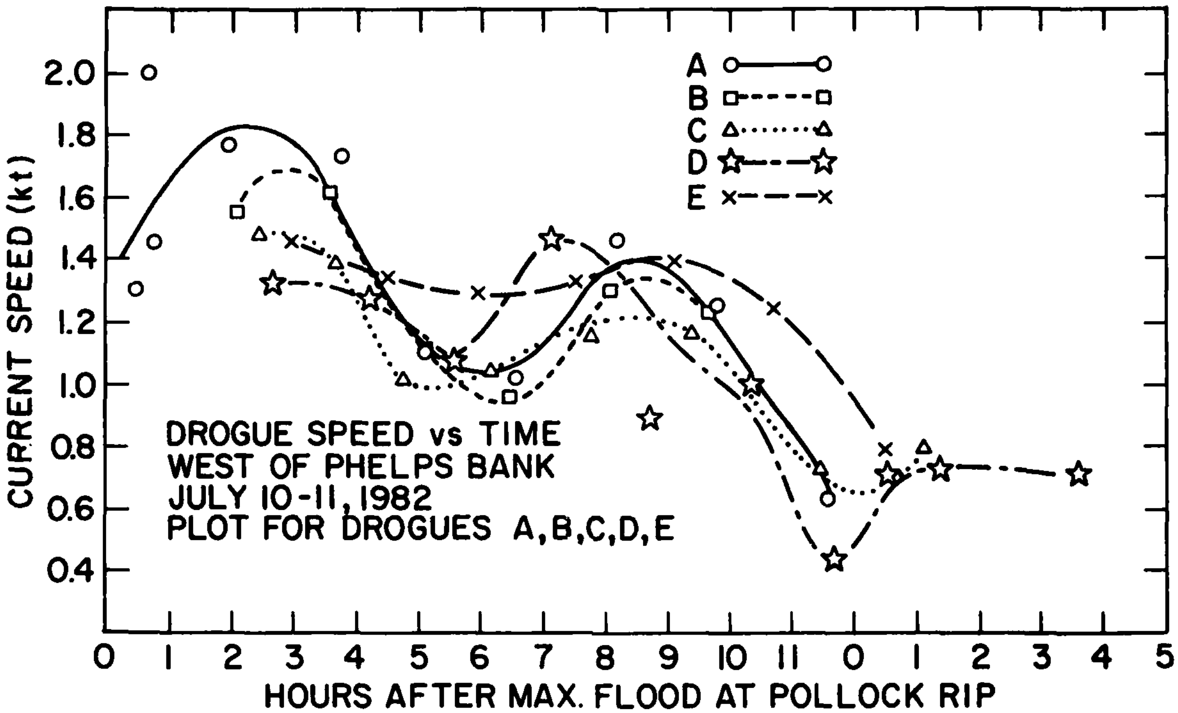

Fig. 9 - Speeds of drogues A,B,C,D,E west of Phelps Bank estimated graphically, point to point between sightings. The time is plotted relative to the maximum flood tide at Pollock Rip as in the standard tidal current tables (NOAA, 1981).

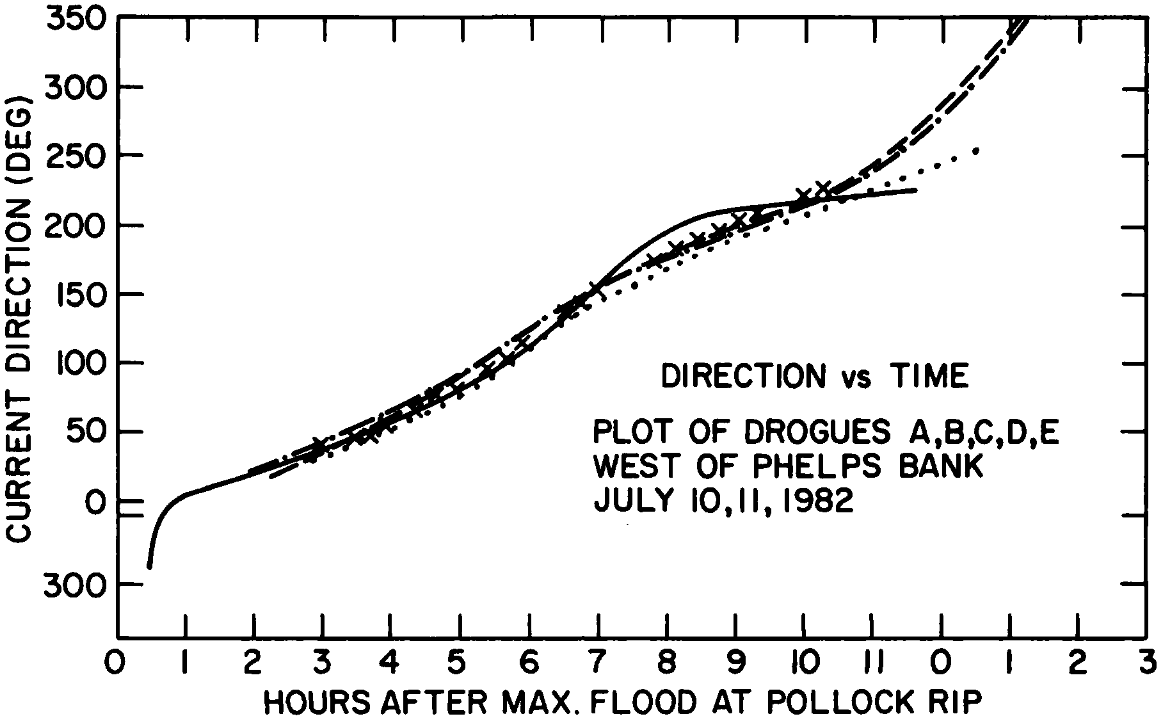

Fig. 10- Speeds of drogues A,B,C,D,E west of Phelps Bank as a function of time after the maximum flood current at Pollock Rip (NOAA, 1981). The directions are based on point to point graphical estimates.

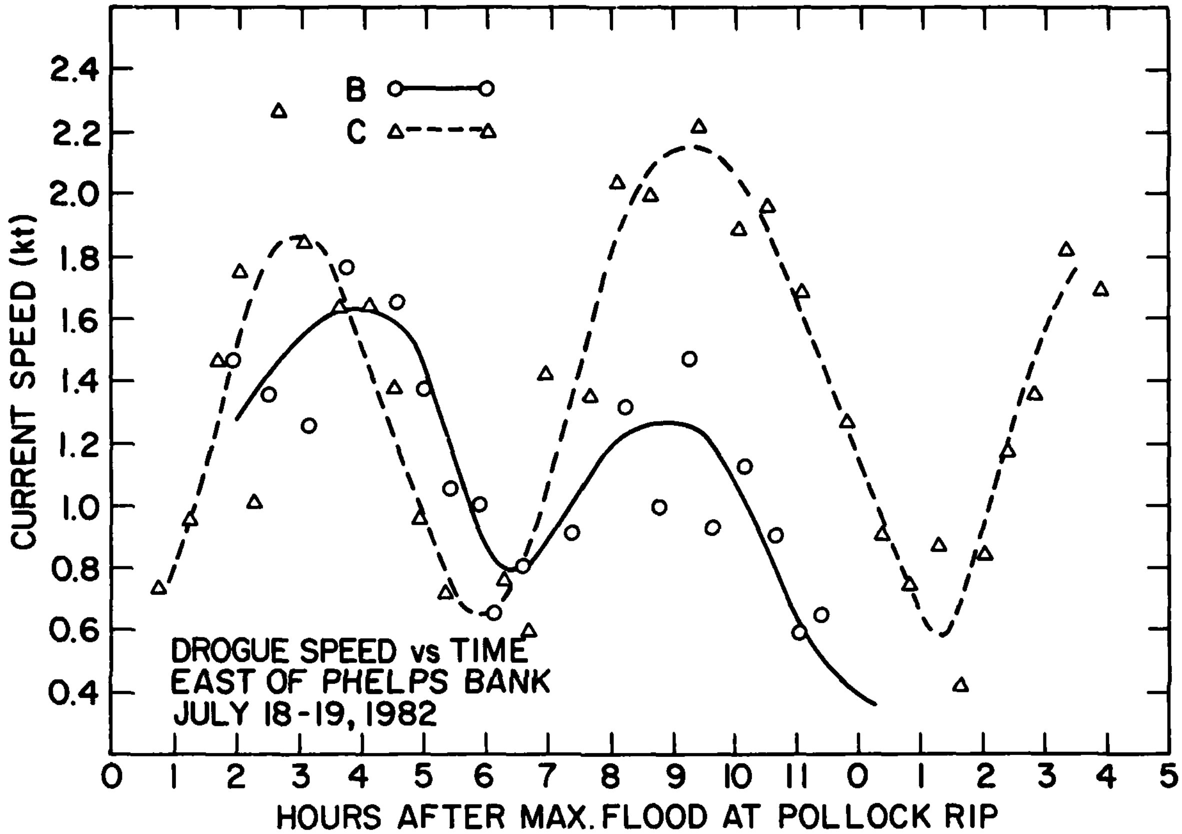

Fig. 11- Speeds of drogues B and C east of Phelps Bank plotted against the time after maximum flood current at Pollock Rip (NOAA, 1981). The speeds are point to point graphical estimates.

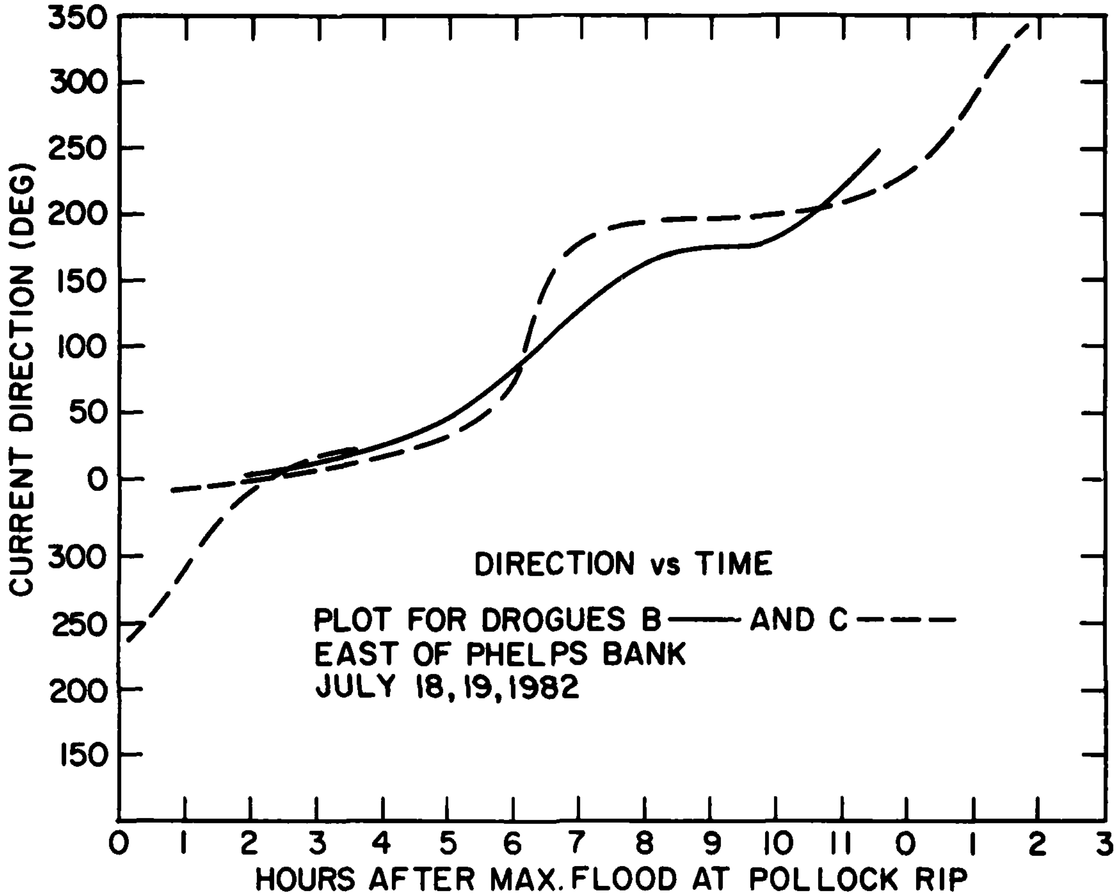

Fig. 12- Directions of drogues B and C east of Phelps Bank as a function of time after maximum flood current at Pollock Rip (NOAA, 1981). The directions are based on point to point graphical estimates.

Based on simple, graphical treatment of the data presented here, two tide tables can be produced for the current speeds and directions in the vicinity of Phelps Bank. The times are expressed in terms of maximum flood tide at Pollock Rip which are published in the standard NOAA Tidal Current Tables. This allows computation and prediction of the tidal currents at Phelps Bank for any day of the year by following the procedure described in the NOAA Tables. The table west of the bank (Table 10) is for a location centered at approximately 40°47'N-69°25'W; the one east of the bank (Table 11) is for 40°53'N-69°09'W.

In order to improve the accuracy of the tidal estimates and provide a quantitative interpolation of drogue positions between sightings, a computer program was designed to treat the raw data over those segments of the trajectories considered appropriate. The basic assumption in the data treatment was that in this area, where the currents are known to be dominated by rotary tides (that is, the currents are characterized by the absence of slack water), the drogue paths will be elliptical.

During the initial eight hours after deployment on July 10, 1982, the drogues were observed to follow approximately elliptical paths. A program (ELIPS) was developed which allowed ellipse size, axes, and orientation to be varied, and graphical output produced. Using this program in conjunction with a plot of the drogue sightings, ellipse parameters were adjusted to produce a best fit. The starting point on the ellipse was also adjusted to agree with the first sighting. The results of this process are shown in Figures 13 - 17 in which the lengths of the cross arms are approximately equal to the accuracy of measurement for the drogue positions which the crosses represent. The angular position for

Table 10. Tidal currents west of Phelps Bank 40°47'N - 69°25'W. Time is in hours after maximum flood current at Pollock Rip

Time	Direction	Velocity(kt)
0	265	.6
1	325	1.1
2	020	1.5
3	035	1.5
4	055	1.3
5	085	1.1
6	120	1.1
7	150	1.2
8	180	1.3
9	200	1.3
10	215	1.1
11	235	.8

Table 11. Tidal currents east of Phelps Bank 40°53'N - 69°09'W. Time is in hours after maximum flood current at Pollock Rip

Time	Direction	Velocity(kt)
0	250	.7
1	325	.7
2	355	1.2
3	010	1.7
4	020	1.5
5	040	1.2
6	075	.7
7	150	1.0
8	180	1.5
9	190	1.7
10	195	1.6
11	215	1.2

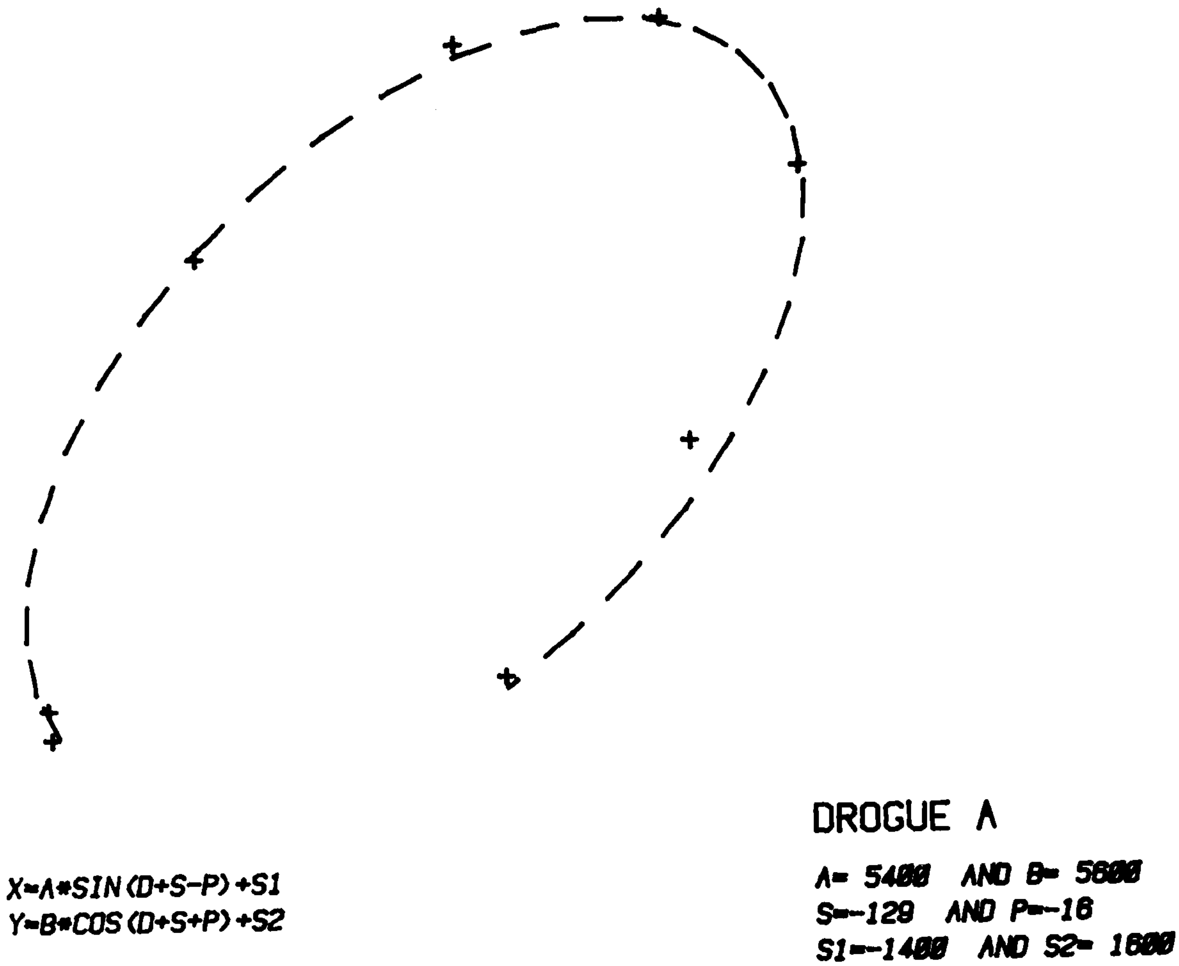

Fig. 13- Computer interpolation of the trajectory of drogue A west of Phelps Bank based on an assumed elliptical path. The crosses are drogue sightings.

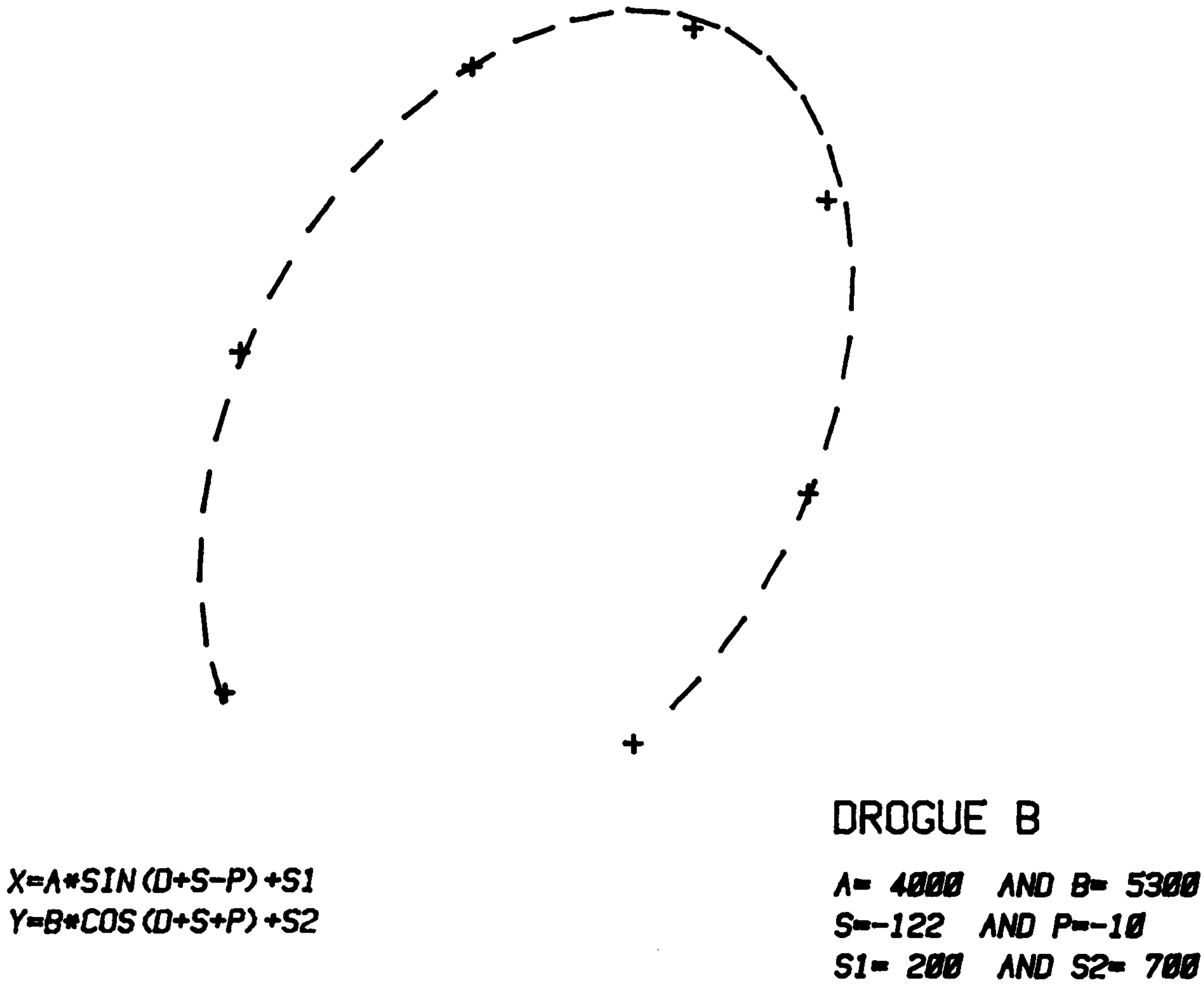

Fig. 14- Computer interpolation of the trajectory of drogue B west of Phelps Bank based on an assumed elliptical path. The crosses are drogue sightings.

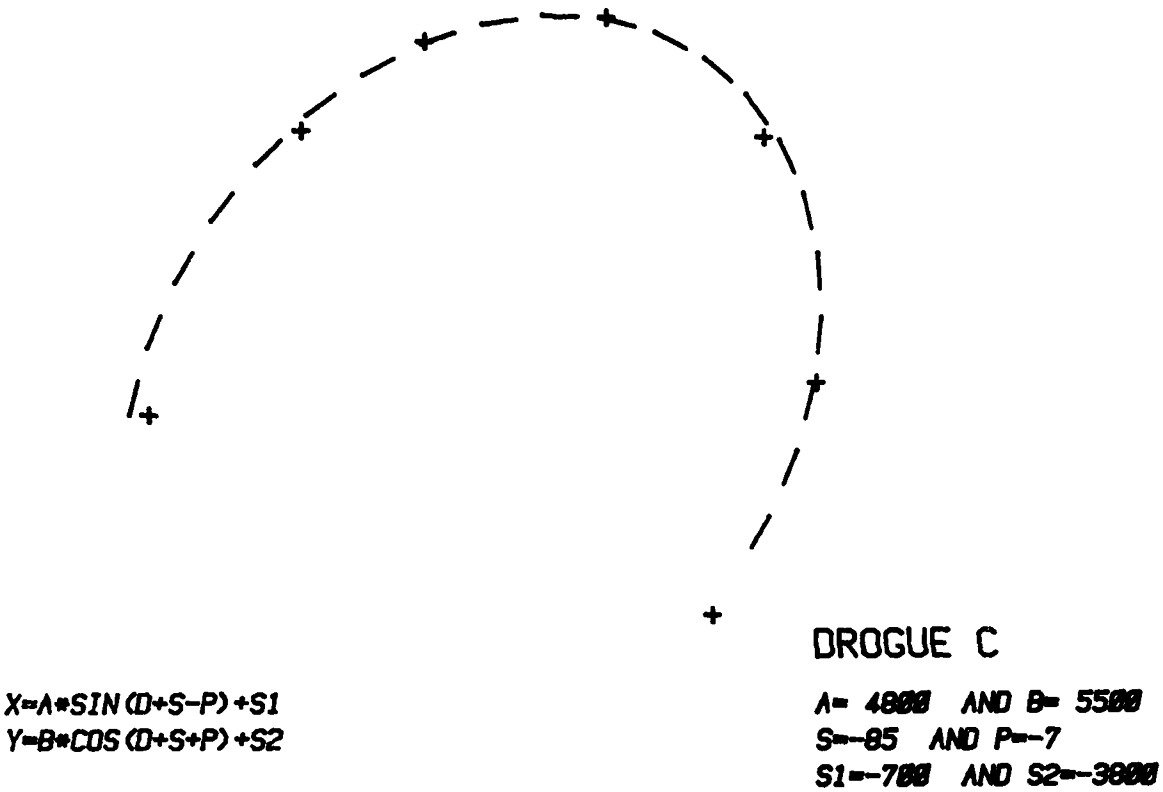

Fig. 15- Computer interpolation of the trajectory of drogue C (at 18 m depth) west of Phelps Bank based on an assumed elliptical path. The crosses are drogue sightings.

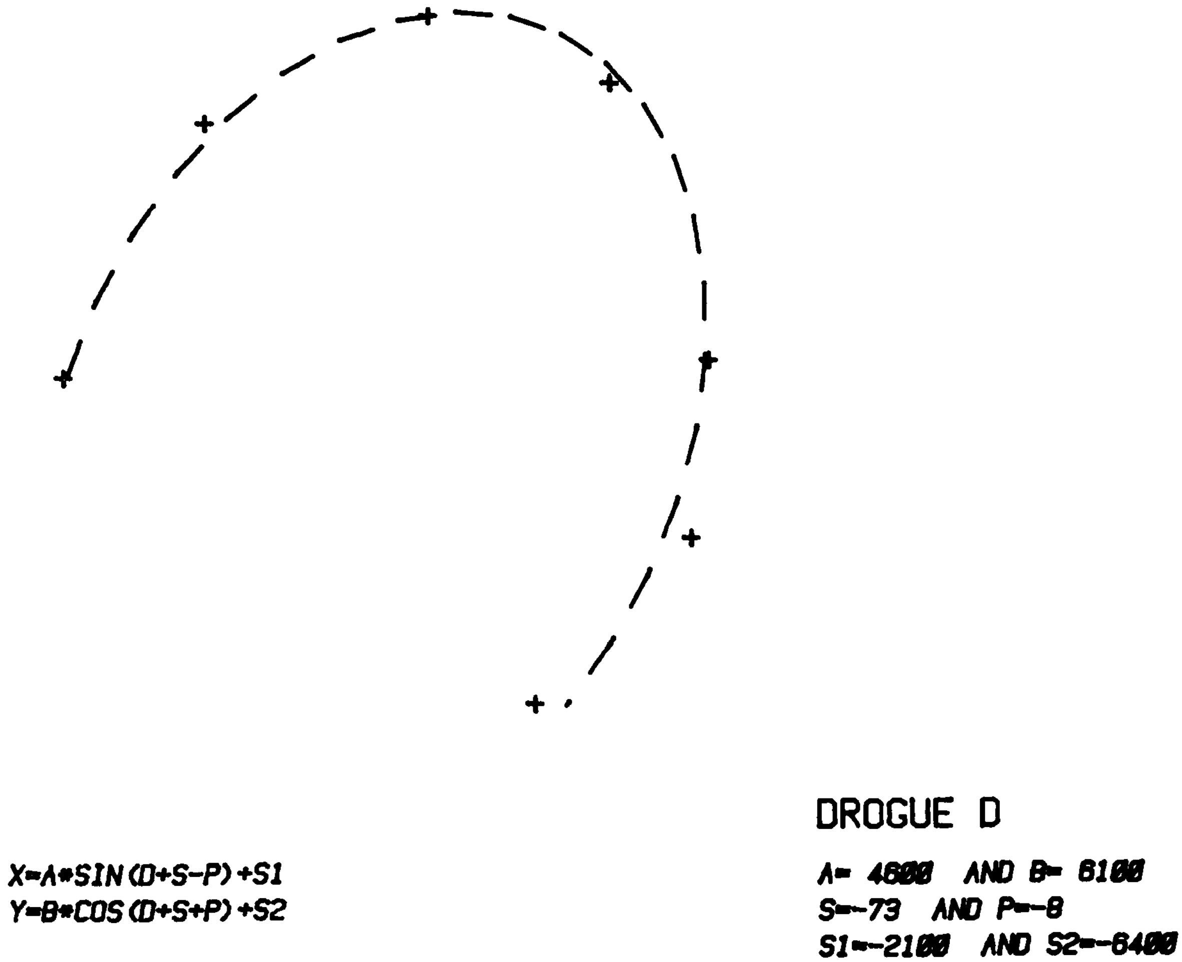

Fig. 16- Computer interpolation of the trajectory of drogue D west of Phelps Bank based on an assumed elliptical path. The crosses are drogue sightings.

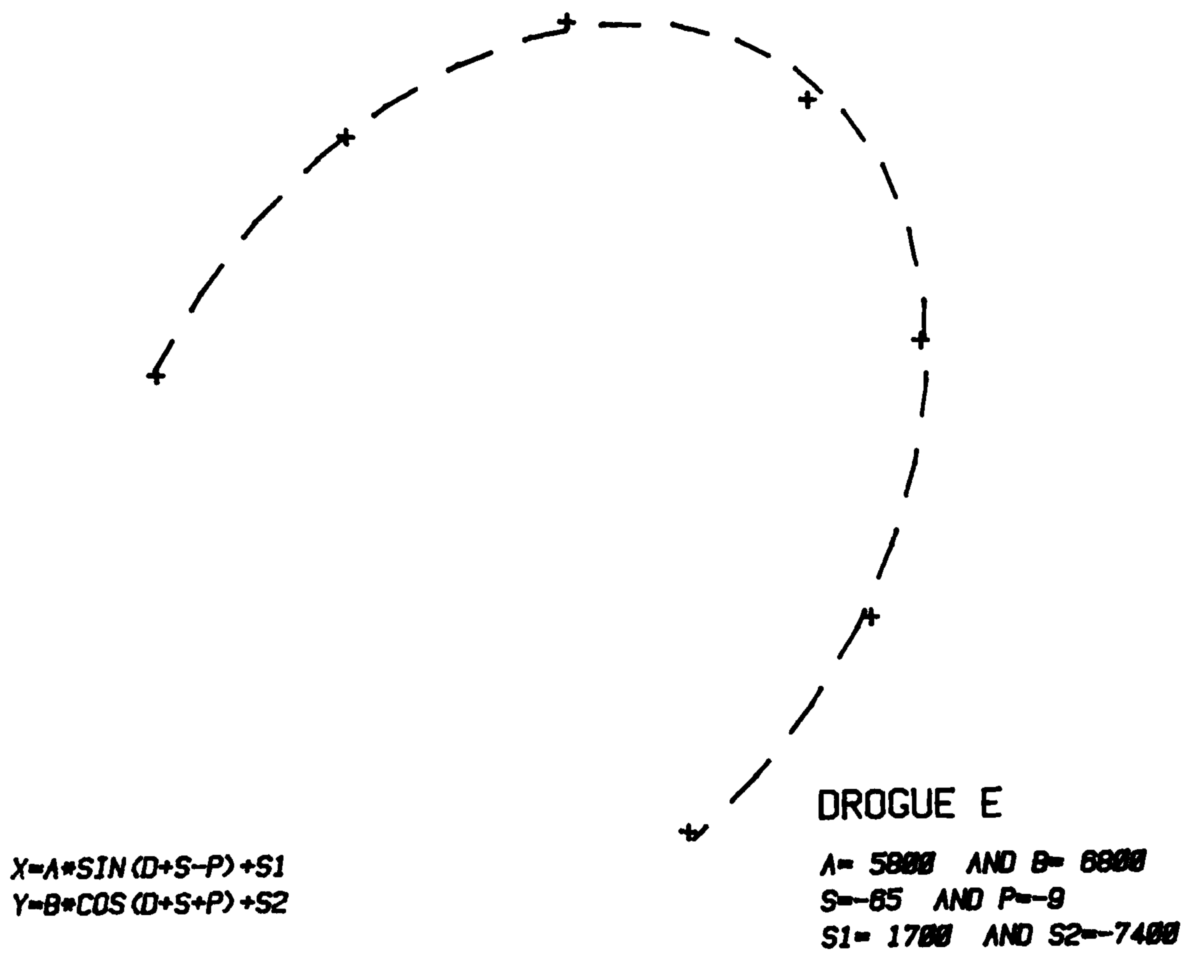

Fig. 17- Computer interpolation of the trajectory of drogue E west of Phelps Bank based on an assumed elliptical path. The crosses are drogue sightings.

each sighting was then found (program BTIME) and with sighting times, an angular speed was calculated between each of the observed drogue positions Half hourly positions were then found for each drogue along its elliptical path using the angular speed between sightings and the time difference since the time of the previous sighting (Program EQUI-T).

It should be noted that the calculated speeds used to set half hourly drogue positions are discontinuous across observed sightings, a situation which is not likely to occur at sea. The computed speeds are therefore incorrect close to observed drogue positions. It is at just these locations that a calculated position should be most nearly correct due to its closeness to an actual observation. Thus, no attempt was made to smooth the speeds, and it is believed that as a first approximation, the calculated half hourly drogue positions are correct to within the order of 100 m. The programs developed for this data treatment are given in APPENDIX A.

The geometrical parameters of the computer-fitted ellipses (Figures 13-17) are presented in Table 12.

Table 12: Determination of ellipse axes.
The angles are relative to North.
Lengths are in meters.

DROGUE	MAJOR	MINOR	ANGLE
A	6806	3769	43
B	5611	3551	27
C	5829	4395	31
D	6350	4247	23
E	7325	5121	32

Periferal lengths of the ellipses were: A = 33867, B = 29108, C = 32236, D = 33581, E = 39357. However, because the drogues only traveled over a

part of each ellipse, and not necessarily at the same speeds, these periferal lengths are not a very good measure of the relative distances traveled by each drogue. A more meaningful value is the path lengths during the time interval when all drogues could be represented by elliptical paths. These are:

A = 19461 B = 18296 C = 16369 D = 16432 E = 18875

That path C is shortest is apparent, but whether this can be attributed to vertical shear caused by bottom drag or is merely due to statistical variation is not clear. An examination of the plot of speed as a function of time during this interval is also inconclusive on this point. Because the four surface drogues show no marked horizontal shear, either in the north or east direction, their path lengths or speeds can be averaged. When this is done, the length of path C appears just significantly shorter than the average path length for the surface drogues. Lengths are:

Average	18423
C	16369
Difference	2054
Ave. of all 5	18012
Variation	+1448, −1644

A similar result can be seen from the speed plot when the average speed for the four surface drogues is compared to that for drogue C. The difference is about 10 cm/sec leading to a shear value of $6 \times 10^{-3} sec^{-1}$, a value consistent with those usually found near the ocean surface. However, in the case of a shallow-water environment such as this, it is not clear whether the apparent shear is attributable to wind forces or bottom drag effects.

Since the wind at the time was very light (3 $msec^{-1}$ at 10 m height) and in view of the fact that the hydrographic records show essentially homogeneous water from surface to bottom, the shear (if real) is probably associated with the influence of the sea bottom.

Once the drogue sightings had been computer fitted to elliptical paths and the geometrical parameters of the ellipses established, it was possible to calculate the speed and direction of the Lagrangian current at any point on the ellipses. This data can then be used to generate a tide table. On July 10, 1982 maximum flood tide at Pollock Rip occurred at 0858 EST or 1358 UT. The interval during which all five drogues could be considered as following elliptical paths began at 1630 UT that day and continued for eight hours. Thus, a partial tide table could be calculated between three and ten hours after the reference maximum flood. To find the necessary speed and direction at hourly intervals beginning at 1558, the position of each drogue was calculated using program EQUI-T (See Appendix). The positions were computed on the hour and at a point four minutes before the hour, thus the speeds and directions calculated from each of these pairs of positions was representative of a time two minutes before each hour. The average speed and direction of all five drogues was used to produce the resulting tide table (Table 13) with speed expressed in knots for comparison with other tables. It is seen that the tidal currents derived from computer-fitted ellipses (Table 13) are in good agreement with the information obtained graphically (Table 10). However, within the applicable time range the data in Table 13 are probably more accurate because the interpolation technique allows speed and direction to be computed at each hour.

Table 13. Tidal currents west of Phelps Bank 40°47'N-69°25'W derived from computer-fitted elliptical drogue trajectories. Time is in hours after maximum flood current at Pollock Rip.

Time	Direction	Velocity(kt)
3	36	1.53
4	55	1.46
5	80	1.18
6	115	1.08
7	153	1.20
8	182	1.32
9	200	1.22
10	214	1.22

Computer-fitted interpolation of the buoy trajectories also allows observation of the relative motions of the near-surface drogues (6 m depth). The progressive motions of a group of three drogues can be conveniently observed from a plot in which a triangle connecting the drogue positions is drawn for each hour. In Figures 18-21 this has been done for the trios ABE, ABD, ADE, and BDE. The line marked "Phelps Bank" represents the approximate position and extent of the bank's highest point. It appears from these figures that the presence of the bank retards to some extent the eastward motion of drogue A and particularly B. This can be seen fairly clearly in Figure 19 (ABD). Here as the drogues approach the bank's westward protrusion, drogues A and B slow their eastward motion relative to drogue D. That the bank represents a barrier to eastward motion is also indicated by the eastward travel of drogue E. Its trajectory takes it somewhat south of the bank's southern tip. Figure 18 (ABE) shows drogue E moving further eastward, and for a longer time than A or B. There is also the suggestion that flow around the southern tip of

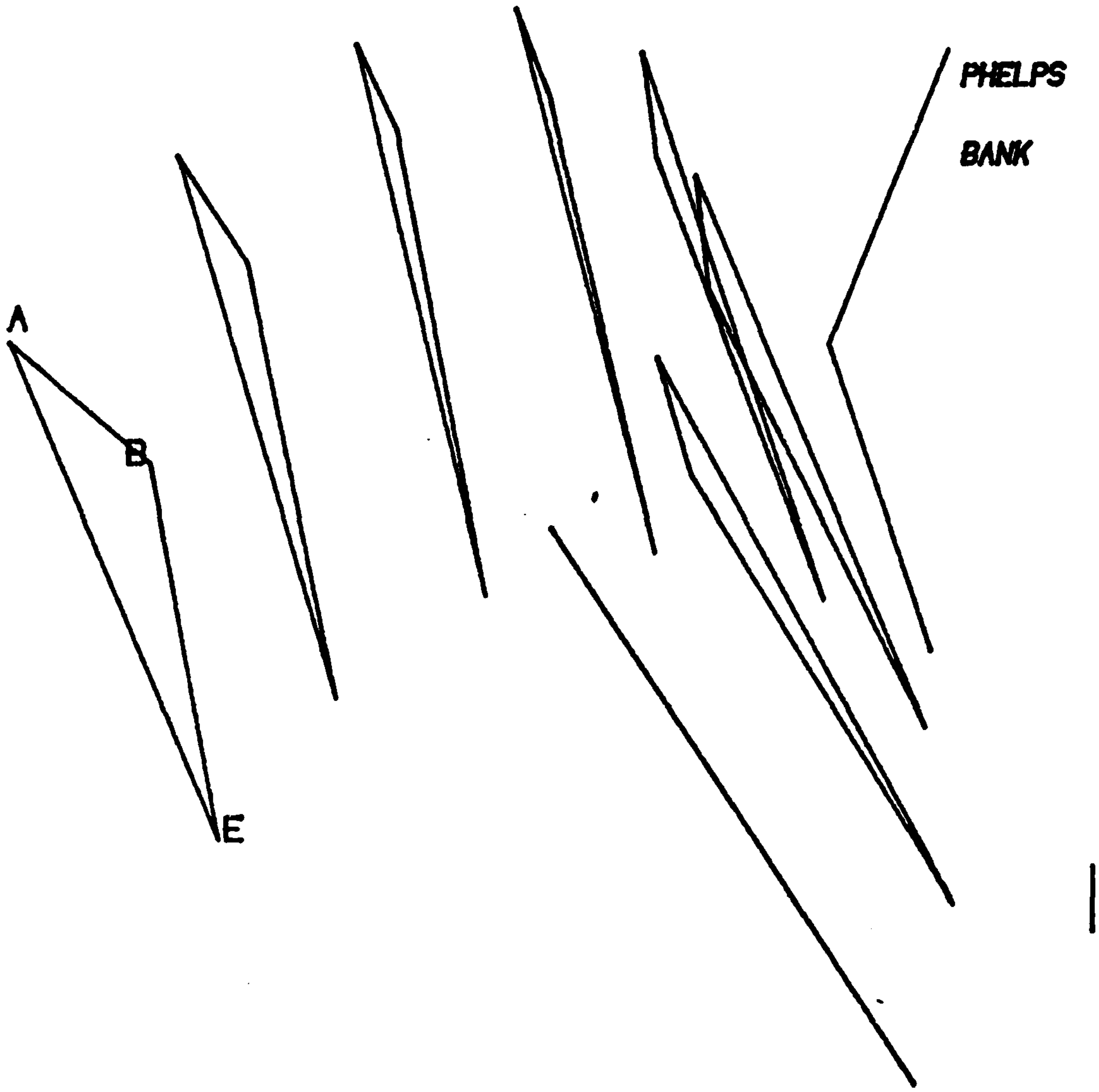

Fig. 18- Hourly positions of the drogue triad ABE based on elliptical interpolation.

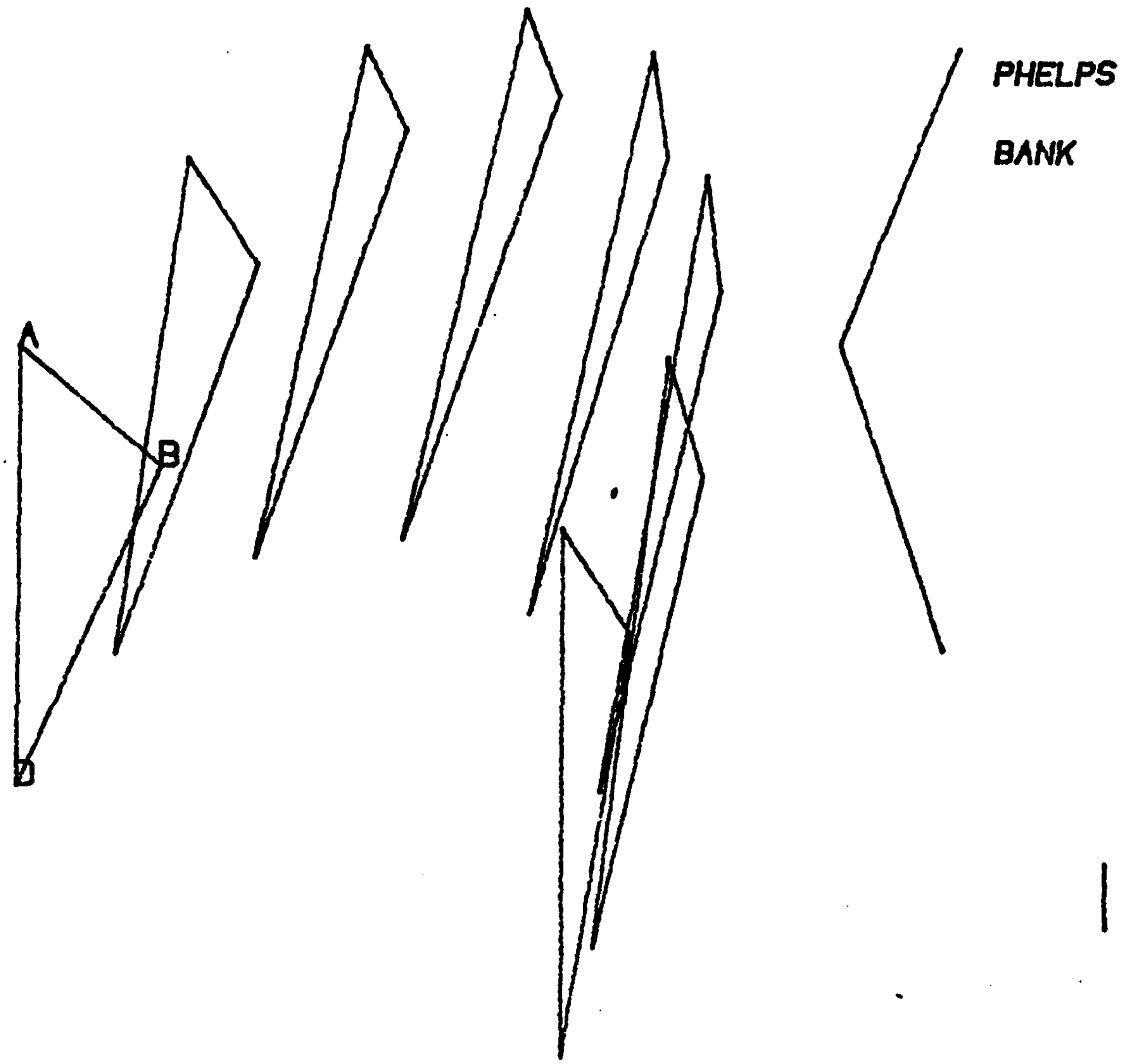

Fig. 19- Hourly positions of the drogue triad ABD based on elliptical interpolation.

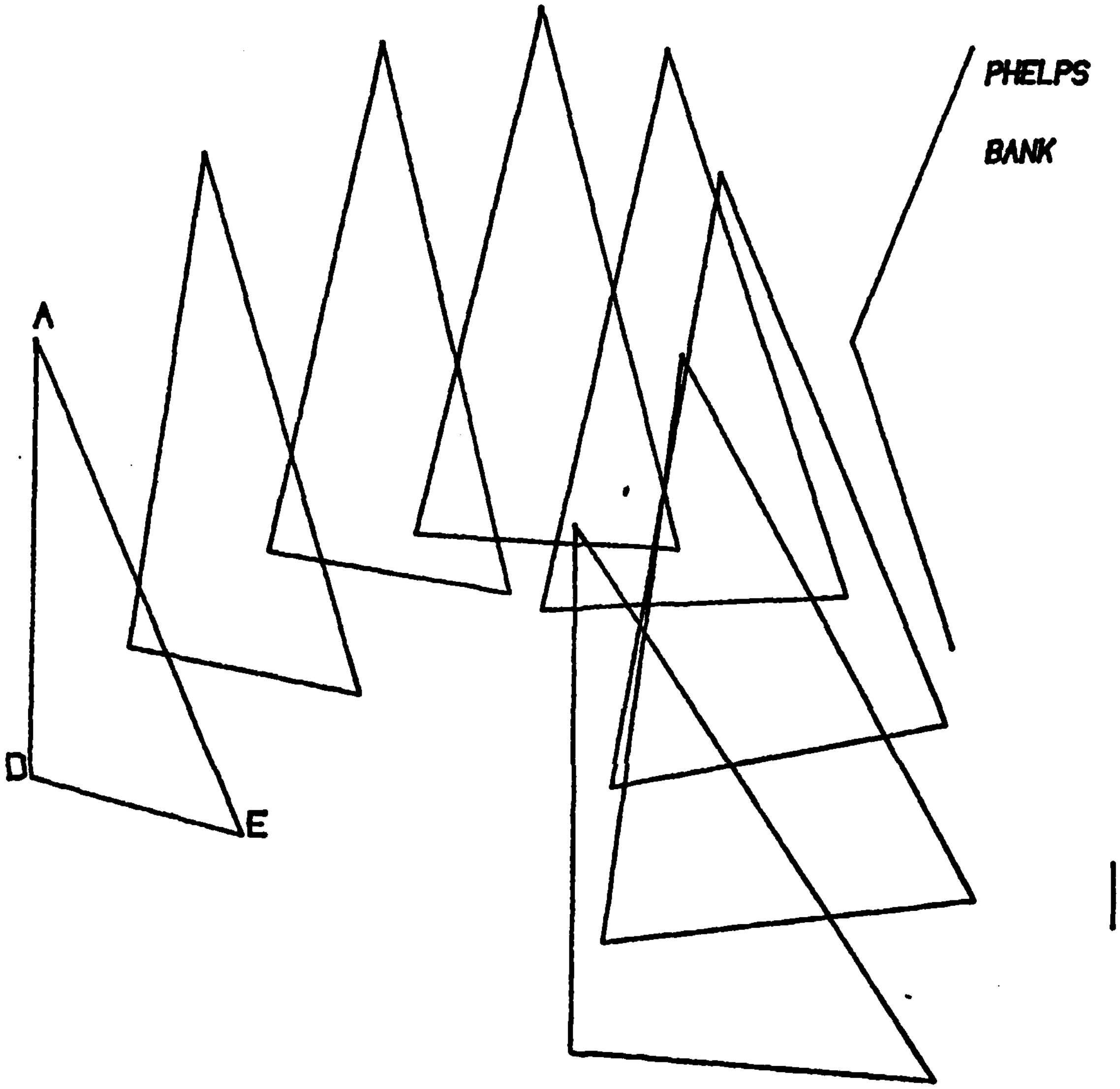

Fig. 20- Hourly positions of the drogue triad ADE based on elliptical interpolation.

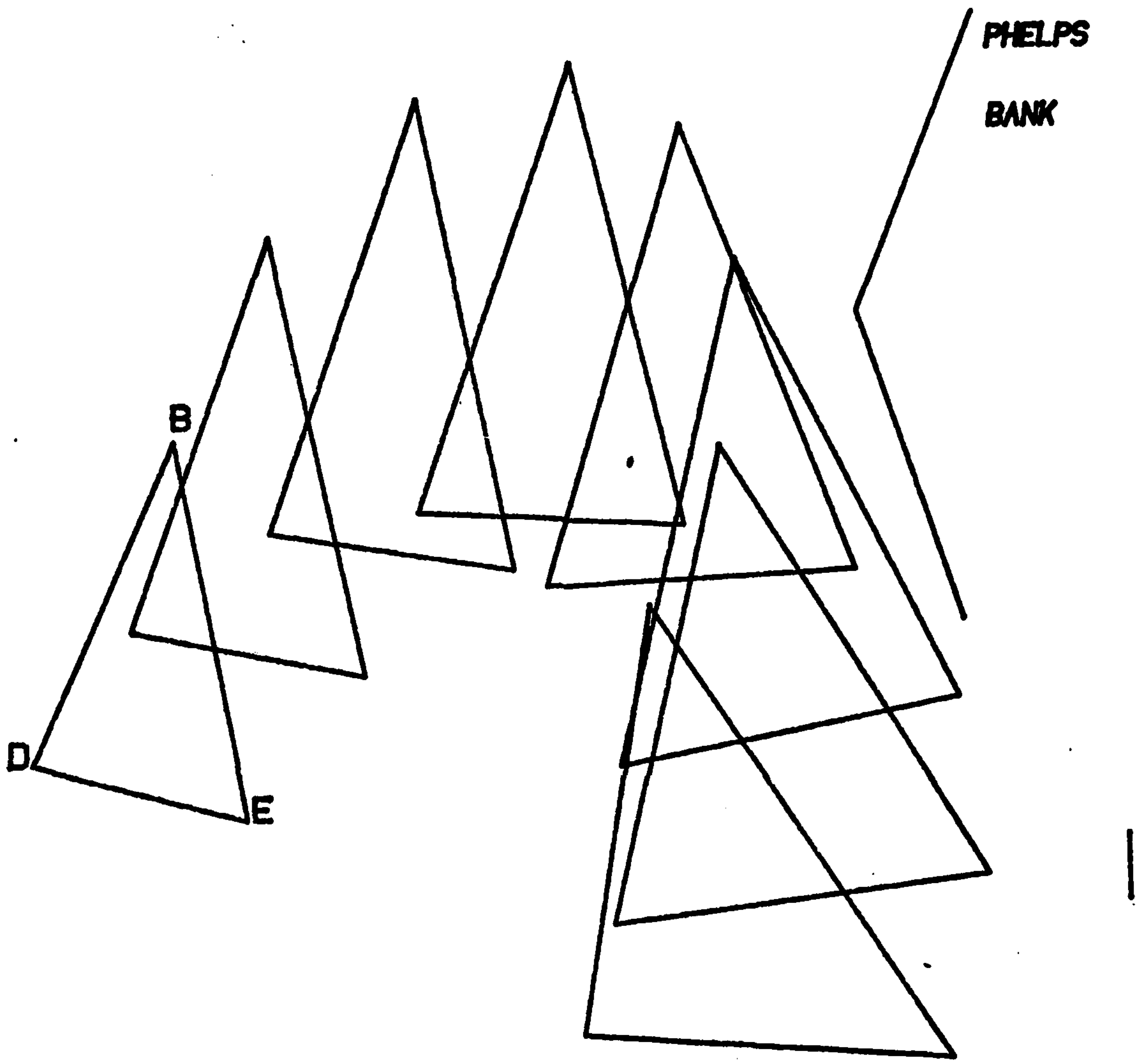

Fig. 21- Hourly positions of the drogue triad BDE based on elliptical interpolation.

the bank is more energetic than the flow somewhat westward, as shown by the steadily increasing distance between drogues D and E, Figures 20 and 21 (ADE and BDE). It therefore appears from these limited measurements that the North-South trending bank inhibits East-West tidal flow, with correspondingly enhanced flow around its southern (and presumably northern) ends.

Additional evidence of the qualitative influence of the bank on the local current pattern was obtained from a quasi-Lagrangian current measurement using the ship (USNS HAYES) as a drifter. On July 21, 1982 the USNS HAYES traversed Phelps Bank with all engines stopped. Table 14 lists navigational and bathymetric data at two minute intervals for this pass across Phelps Bank. The basic premise in this measurement is that the USNS HAYES (keel depth 5.8 m) acts as a Lagrangian drifter when not under power, that is, the progressive series of LORAN-C fixes (Table 14) recorded aboard ship represent motion of the ocean current only. For this premise to be valid, it must be assumed that no other forces are acting on the ship. The only other force of any consequence would be the wind acting on the superstructure of the ship as a sail. Table 15 provides information on the relationship of the ship course, ship heading and the wind while traversing the bank. It is seen from the table that both the ship heading as well as the wind speed and direction remained relatively constant during the drift across the bank, that is, the wind remained on the starboard quarter. This is interpreted to mean that the wind effect is constant and if it has any influence, it will be a steady southerly displacement of the ship track. Such an effect could be subtracted out if the ship movement were known as a function of wind speed alone. Therefore,

Table 14. Depths, positions and ship speeds
July 21, 1982

Time (U.T.)	Speed ($MSEC^{-1}$)	Depth (M)	N. Latitude	W. Longitude
0943	1.09	29.0	40° 49.96'	69° 19.74'
0945	1.03	28.0	40° 49.93'	69° 19.82'
0947	1.01	25.5	40° 49.91'	69° 19.90'
0949	.93	26.0	40° 49.89'	69° 19.97'
0951	.85	25.0	40° 49.88'	69° 20.04'
0953	.82	24.0	40° 49.87'	69° 20.13'
0955	.91	24.0	40° 49.84'	69° 20.21'
0957	.92	23.5	40° 49.81'	69° 20.26'
0959	.88	23.5	40° 49.77'	69° 20.32'
1001	.87	23.0	40° 49.74'	60° 20.39'
1003	.82	23.0	40° 49.71'	60° 20.45'
1005	.86	23.0	40° 49.69'	60° 20.52'
1007	.92	23.5	40° 49.66'	60° 20.60'
1009	.83	23.5	40° 49.63'	60° 20.65'
1011	.77	23.5	40° 49.61'	69° 20.71'
1013	.65	24.0	40° 49.59'	69° 20.77'
1015	.67	23.5	40° 49.58'	69° 20.82'
1017	.76	24.5	40° 49.55'	69° 20.87'
1019	.71	23.5	40° 49.52'	69° 20.94'
1021	.65	22.5	40° 49.50'	69° 20.98'
1023	.65	22.0	40° 49.49'	69° 21.03'
1025	.67	23.5	40° 49.48'	69° 21.10'
1027	.70	24.5	40° 49.45'	69° 21.16'
1029	.69	23.0	40° 49.42'	69° 21.20'
1031	.62	23.5	40° 49.41'	69° 21.24'
1033	.50	22.5	40° 49.41'	69° 21.28'
1035	.50	18.4	40° 49.40'	69° 21.33'
1037	.55	31.5	40° 49.37'	69° 21.37'
1039	.50	37.0	40° 49.36'	69° 21.41'
1041	.36	38.5	40° 49.35'	69° 21.42'
1043	.32	39.5	40° 49.34'	69° 21.46'
1045	.35	40.5	40° 49.33'	69° 21.49'
1047	.35	41.5	40° 49.32'	69° 21.52'
1049	.22	41.0	40° 49.32'	69° 21.54'
1051	.21	41.5	40° 49.32'	69° 21.55'
1053	.26	41.5	40° 49.31'	69° 21.58'
1055	.26	42.0	40° 49.29'	69° 21.59'
1057	.21	41.5	40° 49.30'	69° 21.61'
1059	.10	42.0	40° 49.30'	69° 21.63'
1101	.26	42.0	40° 49.29'	69° 21.66'
1103	.26	42.0	40° 49.29'	69° 21.69'
1105	.26	42.0	40° 49.27'	69° 21.70'
1107	.15	42.0	40° 49.28'	69° 21.71'

Table 14. Depths, positions and ship speeds
July 21, 1982 (Cont)

Time (U.T.)	Speed ($MSEC^{-1}$)	Depth (M)	N. Latitude	W. Longitude
1109	.10	42.5	40° 49.28	69° 21.73'
1111	.15	42.0	40° 49.28'	69° 21.75'
1113	.21	42.0	40° 49.27'	69° 21.77'
1115	.21	42.0	40° 49.27'	69° 21.78'
1117	.05	41.0	40° 49.28'	69° 21.78'
1119	.05	40.5	40° 49.28'	69° 21.79'
1121	.00	40.5	40° 49.28'	69° 21.81'
1123	.10	40.0	40° 49.29'	69° 21.84'
1125	.10	40.0	40° 49.29'	69° 21.85'
1127	.05	40.0	40° 49.30'	69° 21.84'
1129	.15	40.0	40° 49.31'	69° 21.84'

Table 15. Wind conditions and ship heading during a pass over Phelps Bank (July 21, 1982)

Time (U.T.)	Course (Deg)	Ship Hdng	Wind Speed	Wind Dir
0945			7.3	2.8
0947	246			
0949	250			
0951	256			
0953	257			
0955	254			
0957	250			
0959	237			
1001	233		7.8	326
1003	236			
1005	245			
1007	244			
1009	241			
1011	240			
1013	236			
1015	244	190°	9.5	347.4
1017	245	220°		
1019	237	235°		
1021	238	230°		
1023	248	210°		
1025	257	200°		
1027	242	220°		
1029	236	240°		
1031	243	240°	9.9	354.5
1033	249	220°		
1035	257	220°		
1037	248	235°		
1039	237	235°		
1041	248			
1043	258	220°		
1045	236	240°	9.8	3.9
1047	243	250°		
1049	251	230°		
1051	267	220°		
1053	256	240°		
1055	242	260°		
1057	231	250°		
1059	251	240°		
1101	272		10.4	7.9
1103	251	270°		
1105	234	270°		
1107	246	250°		
1109	286	240°		

Table 15. Wind conditions and ship heading during a pass over Phelps Bank (July 21, 1982) (Cont)

Time (U.T)	Course (Deg)	Ship Hdng	Wind Speed	Wind Dir
1111	264	250°		
1113	249			
1115	257	270°	10.3	13.5
1117	281	250°		
1119	335	240°		
1121	265	250°		
1123	266	260°		
1125	267	270°		
1127	312	260°		
1129	248	240°		

Note: 1) Ship engines stopped at 0938
2) Wind speed is in meters per second
3) Wind direction and ships course and heading are in degrees
4) Wind speeds and directions are 15 minute averages

based on this rather qualitative argument, it is considered that the ship drift is probably linearly related to the current.

The information in Tables 14 and 15 is summarized and correlated graphically in Figures 22 and 23. The bathymetric profile of the bank along the drift track is shown in both figures for common reference. Figure 22 shows a segment of the drift track, plotting LORAN-C positions at 4 or 8-minute intervals. The "wind rose" for the duration of the drift is also shown in the figure. It should be noted that the wind remains constant within about ± 25° in direction and ± 1.5 $msec^{-1}$ in speed. In Figure 23 the observation of primary interest is the current variation relative to the topography of Phelps Bank, namely, there is a marked change in current (ship drift) speed correlated with the leeward edge of the bank. A particularly noticeable dynamic feature is the rather abrupt change in the East-West current speed (U) gradient around Longitude 69°21.15'. $\frac{dU}{dx}$ undergoes a change of approximately a factor of five at this point. Upstream of the break point $\frac{dU}{dx}$ is 0.14×10^{-3} sec^{-1} while the downstream value is 0.66×10^{-3} sec^{-1}. There is some indication that the current changes are attributable to the bank as such. For example, Figure 23 also includes the current that would be predicted in the absence of any topographic feature. This current prediction is based on the trajectory of drogue E and the tide table shown earlier (Table 10). Even though the predicted current may be less than precise, the implication is that current across the shallow part of the bank is faster than would be expected in the absence of the topography while the current in the lee of the sand ridge is slower than anticipated.

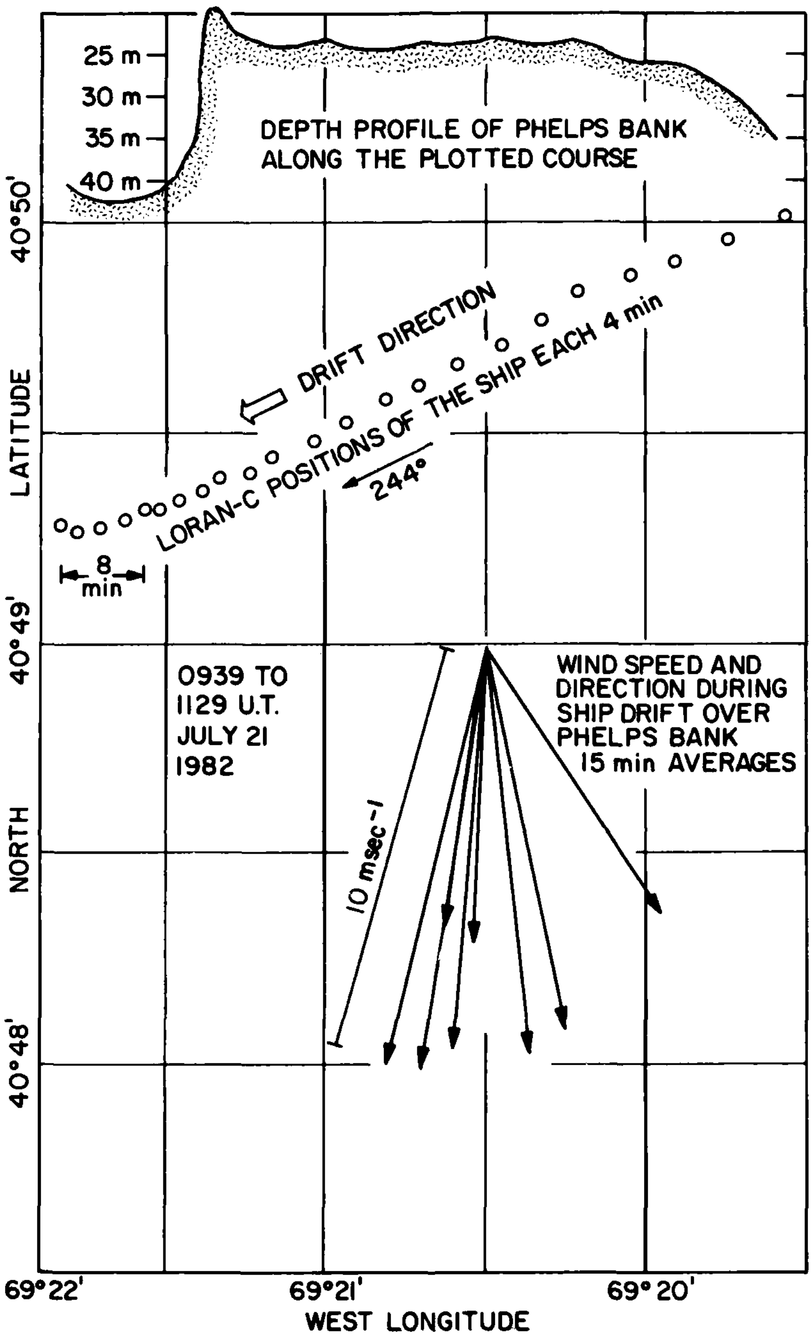

Fig. 22- The USNS HAYES as a Lagrangian drifter moving across Phelps Bank in the tidal current. The plot shows the bathymetry of the bank along the ship's course as well as the wind speeds and directions during the pass.

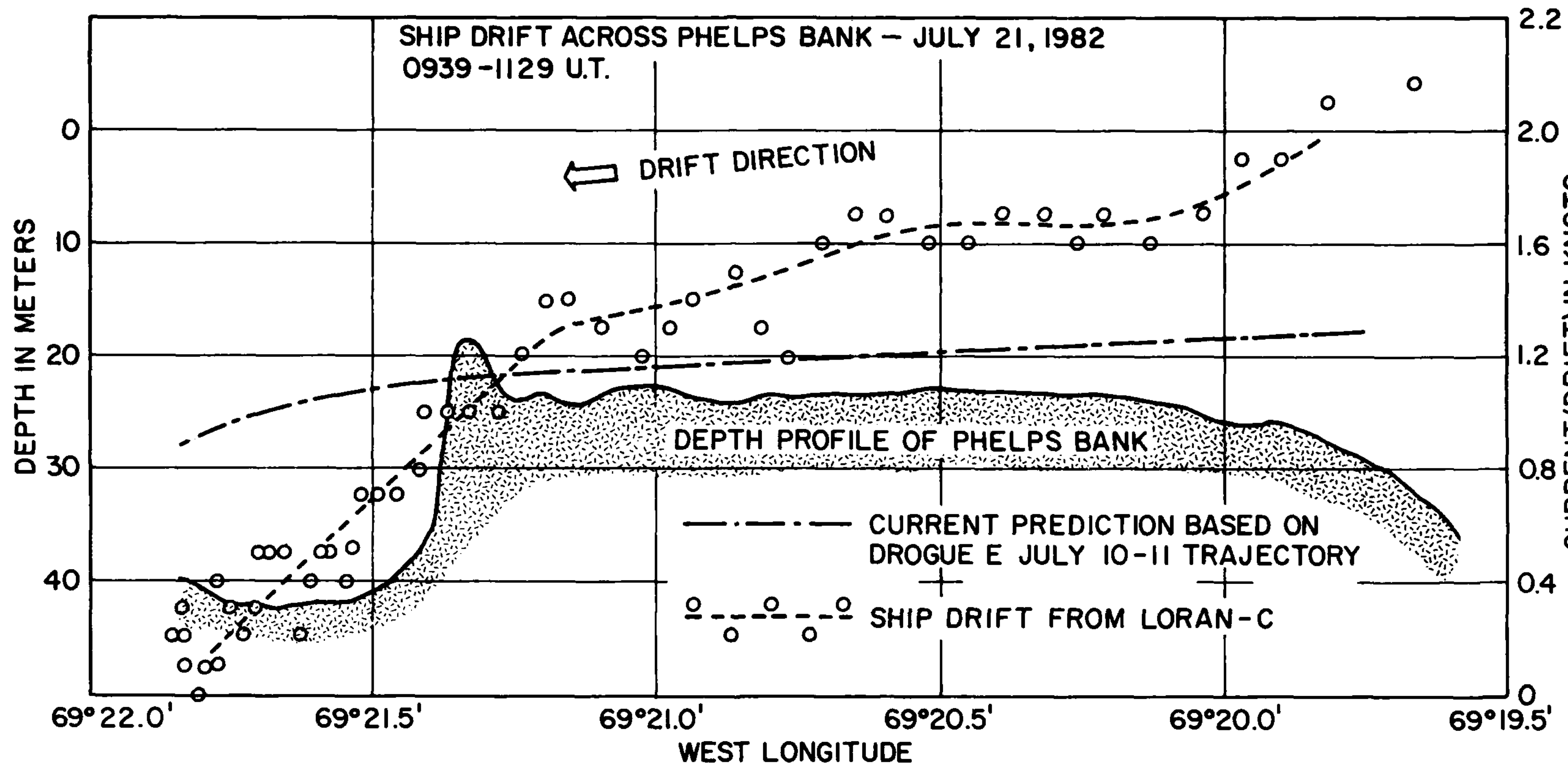

Fig. 23- The speed of the ship drift (Lagrangian current) across Phelps Bank. Shown for comparison is a predicted current based on the trajectory of drogue E (Table 7) and the tide table produced for the area (Table 10).

CONCLUSION

It is clear from the Lagrangian current measurements presented here that the flow near Phelps Bank is dominated by rotary tides following generally elliptical trajectories. This was to be anticipated from the standard tidal tables. However, the current speeds and directions are quite variable in space and time, indicating that real-time current measurements are required for interpretation of any local surface effects attributable to bathymetry. The measurements using both drogues and the USNS HAYES as Lagrangian drifters strongly suggest that variations in bottom topography produce measurable effects on the local surface current pattern.

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REFERENCES

Alpers, W.R., D.B. Ross and C.L. Rufenach (1981). On the Detectability of Ocean Surface Waves by Real and Synthetic Aperture Radar, J. Geophys. Res. 86, No. C7, 6481-6498.

Beal, R.C., P.S. De Leonibus and I. Katz, editors (1981). Spaceborne synthetic aperture radar for oceanography, Johns Hopkins University Press, Baltimore.

Chen, D.T. (1982). Surface Effects Due to Subsurface Processes: a Survey, NRL Memorandum Report 4727, January 15, 1-40.

Cresswell, G.R. (1977). The Trapping of Drifting Buoys by an Ocean Eddy, Deep-Sea Res. 24, 1203-1209.

DeLoor, G.P., and H.W. Brunsveld van Hulten (1978). Microwave Measurements over the North Sea, Boundary-Layer Meteorology, 13, 119-131.

DeLoor, G.P. (1981). The Observation of Tidal Patterns, Currents and Bathymetry with SLAR Imagery of the Sea, IEEE Jour. of Oceanic Eng. OE-6, No. 4, 124-129.

Kirwan, A.D. Jr., G. McNally and S. Pazan (1978). Wind Drag and Relative Separations of Undrogued Drifters, J. Phys. Oceanog. 8 , 1146-1150.

Kirwan, A.D. Jr., G. McNally, M.-S. Chang and R. Molinari (1975). The Effect of Wind and Surface Currents on Drifters, J. Phys. Oceanog. 5, 361-368.

McLeish, W., and D.J.P. Swift, R.B. Long, D. Ross and G. Merrill (1981). Ocean Surface Patterns above Sea-Floor Bedforms as Recorded by Radar, Southern Bight of North Sea, Marine Geology, 43, MI-M8.

McNally, G.J., (1980). The Use of Drogued Satellite Tracked Drifter Buoys to Investigate the Vertical Shear in Surface Currents, Trans. Am. Geophys. Union 61, 990.

Molinari, R.L., M. Spillane, I. Brooks, D. Atwood and C. Duckett (1981). Surface Currents in the Caribbean Sea as Deduced from Lagrangian Observations, J. Geophys. Res. 86, No. C7, 6537-6542.

NOAA (1979). Georges Bank and Nantucket Shoals, National Ocean Survey Chart #13200.

NOAA (1981). Tidal current tables 1982, Atlantic coast of North America, National Ocean Survey Publ.

Richardson, P.L. (1981). Gulf Stream Trajectories Measured with Free-Drifting Buoys, J. Phys. Oceanog. 11, 999-1009.

Vachon, W.A. (1974). Improving Drifting Buoy Performance by Scale Model Drogue Testing, Marine Technology Soc. Jour. 8, 58-62.

Vachon, W.A. (1980). Drifters, in Air-Sea Interaction, Instruments and Methods, F. Dobson, L. Hasse and R. Davis editors, Plenum Press, New York.

Valenzuela, G.R. (1981). A Remote Sensing Experiment in the Nantucket Shoals (SEBEX), IUCRM Symposium on "Wave Dynamics and Radio Probing of the Ocean Surface," Miami Beach, Fla.; submitted for publication in the proceedings, Plenum Press, New York.

APPENDIX A

The following programs were developed for use on the HP 85 computer, but could be used with minor modification on other BASIC language machines.

Program ELIPS

```
 10 DIM X(40),Y(40)
 20 DISP "FINISHED DIDDLING"
 30 INPUT A$
 40 IF A$="YES" THEN 120
 50 DISP "ENTER X-SHIFT,Y-SHIFT"
 60 INPUT S1,S2
 70 DISP "ENTER X-AMP,Y-AMP"
 80 INPUT A,B
 90 DISP "ENTER SHIFT ANGLE"
100 INPUT P
110 P=P/10
120 PENUP
130 SCALE -10000,10000,-15000,0
140 DEG
150 FOR D=0 TO 36
160 X(D)=A*SIN(10*(D-P))+S1
170 Y(D)=B*COS(10*(D+P))+S2
180 PLOT X(D),Y(D)
190 NEXT D
200 PAUSE
210 IF A$="YES" THEN 280
220 PEN -1
230 FOR D=0 TO 36
240 PLOT X(D),Y(D)
250 NEXT D
260 PEN 1
270 GOTO 20
280 DISP "NOW GET START POINT"
290 DISP "ENTER START ANGLE"
300 INPUT S
301 S=S/10
310 MOVE S1,S2
320 X=A*SIN(10*(S-P))+S1
330 Y=B*COS(10*(S+P))+S2
340 DRAW X,Y
350 PAUSE
360 MOVE S1,S2
370 PEN -1
380 DRAW X,Y
390 PEN 1
400 DISP "IS OK"
410 INPUT R$
420 IF R$="YES" THEN 440
430 GOTO 290
440 S=10*S @ P=10*P
450 PRINT
460 PRINT "X=A*SIN(D+S-P)+S1"
470 PRINT "Y=B*COS(D+S+P)+S2"
480 PRINT
490 PRINT "A=";A;" AND B=";B
500 PRINT "S=";S
510 PRINT "P=";P
520 PRINT "S1=";S1;" AND S2=";S2
530 END
```

Program BTIME

```
 10 DISP "WHICH BUOY "
 20 INPUT B$
 30 DISP "ENTER X-AMP,Y-AMP"
 40 INPUT A,B
 50 DISP "ENTER X-DISP,Y-DISP"
 60 INPUT S1,S2
 70 DISP "ENTER PHASE SHIFT"
 80 INPUT P
 90 DISP "ENTER START ANGLE"
100 INPUT S
110 DEG
120 DIM L1(15),L2(15),T(15)
121 F$="BUOY"
122 F$[5]=B$
130 L1=2448 @ L2=4166
140 ASSIGN# 1 TO F$
150 READ# 1 ; A$,N
160 FOR I=1 TO N
170 READ# 1 ; T(I),L1(I),L2(I)
180 L2(I)=(L2-L2(I))*COS(L1/60)*
    1830
190 L1(I)=(L1(I)-L1)*1830
200 NEXT I
201 ASSIGN# 1 TO *
210 DISP "N=";N;" ENTER NEW N"
220 INPUT N
221 DISP "Y-SCALE 15000"
222 INPUT S8,S9
230 GCLEAR
240 SCALE -10000,10000,S8,S9
250 FOR I=1 TO N
260 MOVE L2(I)-90,L1(I)
270 DRAW L2(I)+90,L1(I)
280 MOVE L2(I),L1(I)-90
290 DRAW L2(I),L1(I)+90
300 NEXT I
310 PENUP
320 FOR D=0 TO 300 STEP 5
330 X=A*SIN(D+S-P)+S1
340 Y=B*COS(D+S+P)+S2
350 PLOT X,Y
360 PENUP
370 NEXT D
380 Q=2
390 MOVE -9000,S8+1500
400 LABEL "ANGLE "&VAL$(Q)
410 MOVE -9000,S8+500
420 INPUT M
430 MOVE S1,S2
440 X=A*SIN(M+S-P)+S1
450 Y=B*COS(M+S+P)+S2
460 DRAW X,Y
470 MOVE 5000,S8+1500
480 LABEL "IS OK"
490 MOVE 5000,S8+500
500 INPUT R$
510 IF R$="YES" THEN 560
520 MOVE S1,S2
530 PEN -1 @ DRAW X,Y @ PEN 1
540 GCLEAR S8+2200
```

```
550 GOTO 390
560 GCLEAR S8+2200
561 S(Q)=M
562 Q=Q+1
570 MOVE -9000,S9-1000*Q
580 LABEL VAL$(M)
581 IF Q>N THEN 600
590 GOTO 390
600 S(1)=0
610 L$="ELIPS"&B$
611 CREATE L$,1
620 ASSIGN# 1 TO L$
630 PRINT# 1 ; A,B,S1,S2,P,S,N
640 FOR I=1 TO N
650 PRINT# 1 ; S(I)
660 NEXT I
670 ASSIGN# 1 TO *
680 DISP "ELLIPSE NUMBERS FILED"
690 END
```

Program EWUI-T

```
 10 DEG
 20 E$="ELIPS"
 30 D$="BUOY"
 31 F$="DROG-"
 40 DISP "WHICH DROGUE"
 50 INPUT B$
 60 DATA 990,1020,1050,1080,1110
    ,1140,1170,1200,1230,1260,12
    90,1320,1350,1380,1410,1440
 70 ASSIGN# 1 TO E$&B$
 80 ASSIGN# 2 TO D$&B$
 90 READ# 1 ; A,B,S1,S2,P,S,N
100 FOR I=0 TO N-1
110 READ# 1 ; S(I)
120 NEXT I
130 READ# 2 ; A$,M
140 FOR I=0 TO N-1
150 READ# 2 ; T(I),L1,L2
160 NEXT I
170 PRINT T(0);T(N-1)
180 FOR I=1 TO N-1
190 T=T(I)-T(I-1)
200 IF T<0 THEN T(I)=T(I)+1440 @
     GOTO 190
210 G(I)=(S(I)-S(I-1))/T
220 NEXT I
230 CREATE F$&B$,1
240 ASSIGN# 1 TO F$&B$
250 FOR J=1 TO 16
260 READ T
270 FOR I=1 TO N-1
280 IF T>T(I) THEN 350
290 D=(T-T(I-1))*G(I)
300 D=D+S(I-1)
310 X=A*SIN(D+S-P)+S1
320 Y=B*COS(D+S+P)+S2
321 DISP X;Y
330 PRINT# 1 ; X,Y
340 GOTO 360
350 NEXT I
360 NEXT J
370 ASSIGN# 1 TO *
380 END
```

2-8

DT